NASA TECHNICAL NOTE

NASA TN D-2680

NASA TN D-2680

FLIGHT INVESTIGATION OF THE VZ-2 TILT-WING AIRCRAFT WITH FULL-SPAN FLAP

by Robert J. Pegg, Henry L. Kelley, and John P. Reeder

Langley Research Center Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MARCH 1965

FLIGHT INVESTIGATION OF THE VZ-2 TILT-WING AIRCRAFT

WITH FULL-SPAN FLAP

By Robert J. Pegg, Henry L. Kelley,
and John P. Reeder
Langley Research Center

SUMMARY

This report presents the results of a flight-test program conducted at the Langley Research Center on the modified VZ-2 tilt-wing VTOL aircraft. The major modification was the addition of a full-span flap. Other important modifications included a reduction in the roll-control sensitivity for hovering and low-speed flight (0 to 27 knots), and the use of the full-span ailerons for yaw control during hovering and low-speed flight (0 to 56 knots).

The addition of the full-span flap substantially improved the rate-of-descent capability at intermediate wing-tilt angles, although the maximum available flap deflection was only 30°. The high-speed portion of the limiting undary was characterized by the onset of large aircraft motions which required large displacements of the controls to correct. The low-speed portion of the limiting boundary was characterized mainly by directional disturbances and static directional instability.

The use of the aileron arrangement for yaw control on the VZ-2 was judged to be inadequate for landing at low forward speeds and for maneuvers close to the ground. This inadequacy is due to the marginal capability for controlling the aircraft when landing with any forward speed, or when close to the ground at very low speed where the basic aircraft has self-generated disturbances. Different aileron deflection programing with wing tilt, larger ailerons, and larger deflection angles might possibly have provided adequate yaw control moments. The reduction in the previously excessive roll-control sensitivity of 1.07 rad/sec^2/in. to 0.64 rad/sec^2/in. resulted in response characteristics that were judged by pilots to be good.

Other results showed that the flapped wing experienced a change in total lift as the aircraft went in and out of ground effect at high wing angles (60° to 70°). The sudden increase in lift and a nose-up trim change when the aircraft was climbing through about 10 feet altitude caused a tendency for the aircraft to "balloon." Conversely, when descending through an altitude of about 10 feet the aircraft had a tendency to "drop out" as it approached the ground. Although, with the thrust reserve available in this case, the pilot could easily control the rate of sink prior to touchdown for the conditions of these tests, these characteristics may adversely affect the flying qualities,

particularly for short take-off and landing operations under overload conditions, in rough air, or during instrument landings.

INTRODUCTION

The Langley Research Center of the National Aeronautics and Space Administration has been active in tilt-wing VTOL research over the last decade. In-flight and wind-tunnel investigations have been carried out to explore the feasibility of the tilt-wing concept as a means of achieving satisfactory VTOL flight. Areas that have been studied include stability and control (handling qualities), performance, aerodynamics, operational aspects, and loads. Results of some of the work in these areas may be found in references 1 to 12.

Much of the previous tilt-wing flight research has been directed at the stability and control problems which occur during hovering and transition operation (between hovering and approximately 90 knots). The results of this research will aid in the development of satisfactory handling and flying-qualities criteria applicable not only to tilt-wing configurations but also to other VTOL configurations.

This report presents some of the results of a full-scale flight investigation on the VZ-2 tilt-wing research aircraft following several modifications which changed its flying qualities and its aerodynamic characteristics. The primary change was the addition of a full-span, single-slotted flap which was programed with wing-tilt angle or could be independently operated by the pilot. Other changes were a reduction in the roll-control sensitivity, the provision of full-span ailerons for yaw control in addition to the yaw fan, and a drooped leading edge on the wing. The results include the effect of the full-span flap on the rate-of-descent capability, measurements of control sensitivity and angular velocity damping about the roll and yaw axes in hover and low-speed flight, and operational and aerodynamic aspects of STOL problems of the flapped tilt wing near the ground.

SYMBOLS

b	number of rotor blades
c	wing chord, ft
g	acceleration due to gravity, ft/sec^2
I_X	moment of inertia about roll axis, slug-ft^2
I_Y	moment of inertia about pitch axis, slug-ft^2
I_Z	moment of inertia about yaw axis, slug-ft^2

	wing angle (measured from a line parallel to upper longeron), deg
P	power, hp
R	rotor radius, ft
V	airspeed, knots
W	weight of aircraft, lb
α	fuselage angle of attack, deg
δ_f	flap angle, deg

APPARATUS AND PROCEDURE

Aircraft

Aircraft characteristics and modifications.- The VZ-2 VTOL test aircraft has a tilt wing and twin rotors. A three-view drawing of the aircraft including all visible modifications is shown in figure 1. Table I lists the physical characteristics and principal dimensions. Figure 2 is a photograph of the aircraft in transition flight. Power is supplied by a single 850-horsepower gas turbine engine. The pilot has direct control of collective pitch with engine fuel control varying power to maintain essentially a constant rotor speed. Maximum continuous horsepower permitted by the fatigue limits of the transmission system has been increased over previous tests from 630 to 700 horsepower with transients allowable to 800 horsepower.

The primary modification to the aircraft was the addition of a full-span, single-slotted flap located on the trailing edge of the wing. A detailed sketch of the wing and flap is shown in figure 3. The flap consists of two segments, the aft segment of which is a full-span aileron. The flap has a chord of 1.81 feet and the aileron has a chord of 1.20 feet. The maximum flap deflection is 30° and the maximum deflection of the aileron is $\pm 20^{\circ}$. The addition of the full-span flap increased the wing chord from 57 inches to 63 inches. When the flap is fully extended, the planform wing chord is 67 inches. Figure 4 shows the programing of the flap deflection with wing incidence angle. This programing is achieved through a cam mechanism between the wing and flap actuator. The cam was removed after the initial phase of the flight program and a manual flap control was installed to permit the use of wing-flap combinations within the structural envelope.

Other modifications included a reduction in the roll-control sensitivity, the use of full-span ailerons for yaw control in hovering, and an increase in the rotor diameter of 2 inches.

Control-system characteristics.- The aircraft, as tested in this investigation, utilized varying control combinations throughout the conversion. These variations are as follows: (1) Yaw control is obtained in hovering and transition through the use of a fan located vertically in the aft end of the aircraf which operates in conjunction with the full-span ailerons. As the wing angle is reduced and forward speed is increased, the aileron deflections used for directional control are phased out, and yawing moments are obtained solely from the rudder and tail fan. Provisions were made for the pilot to phase out manually the tail-fan blade pitch change with rudder pedal motion; thus, he could regulate the total yawing moment. (2) Pitch control is obtained in hovering by varying the thrust of a fan located in the aft end of the aircraft in the plane of the horizontal tail. As the wing angle is lowered for transition and forward flight, the thrust of the horizontal-tail fan and the deflection of the all-movable horizontal tail with respect to control-stick displacement is reduced. The variation of static thrust of these tail fans with control displacement is undesirably nonlinear. (3) Roll control is obtained by differentially operating the collective pitch of the main rotors during hovering and transition. As the wing angle is decreased and the airspeed is increased, this control is phased out, and roll control by the ailerons is phased in.

Figure 5(a) shows the programing of the aileron deflection for full lateral stick deflection as a function of wing angle, and figure 5(b) shows the aileron deflection for full rudder pedal deflection as a function of wing angle.

Test Conditions

The flight investigation consisted of: (1) attaining aerodynamically limiting steady-state rates of descent at various wing angle and flap angle combinations, (2) basic control sensitivity and angular velocity damping measurements about the roll and yaw axes during hovering and low-speed flight, (3) a study of the effects of ground proximity on the STOL characteristics, and (4) an investigation of the effect of the flap on general aircraft characteristics at transition airspeeds.

The initial familiarization flights were conducted with the flap-cam programing mechanism installed and functioning. Tests were made to determine the rate-of-descent capability, power required, and "loss of lift" in the approach near the ground. The cam was removed after familiarization was attained and a manual system was used for the remaining flight tests.

RESULTS AND DISCUSSION

Rate-of-Descent Limitations

The effect of wing stalling and static directional instability on handling qualities for the aircraft wing without a flap in transition flight is indicated in figure 6(a). This figure shows a region of unsatisfactory flying qualities on a plot of the variation of rate of climb with airspeed. All tests were started at the trim-level-flight airspeed for the particular wing angle and flap setting with a level fuselage attitude. Speed was then held constant while power was slowly varied from maximum to that for which limiting aircraft behavior occurred. Structural limitations, as shown in figure 4, determined the maximum flap settings available. The high-speed side of the boundary curve representing the original wing was determined by abrupt wing dropping, pitch-down, and other symptoms characteristic of conventional aircraft stall behavior; the low-speed side of this curve was determined by excessive buffeting and a lack of sufficient directional control to cope with the static directional instability (as mentioned in ref. 11).

Figure 6(b) shows a similar type of boundary determined for the aircraft with the full-span flap installed on the wing. The use of the full-span flaps greatly improved the original unsatisfactory flight region by moving the boundary down into a region of higher descent velocities and decreasing the airspeed at which the limiting conditions occur. The high-speed portion of this curve is still characterized by conventional aircraft stall behavior, but the effects are less abrupt. In a large region prior to the limiting stall, however, unsteady motions and buffeting limited the ability of the aircraft to be of use operationally. This area is shown in figure 6(b) as the region of increasingly objectionable buffet. As airspeeds decrease during transition, the well-defined lateral and longitudinal disturbances characteristic of airplane-type stalls become progressively milder, and the limiting characteristics tend toward aircraft-induced directional disturbances and instability. The effects of stall and directional instability on handling qualities are critical for the aircraft in the transition condition because it is desirable from an operational standpoint to be able to make landing approaches in a low-speed, partially converted configuration.

Figure 6(c) is taken from reference 11 and may be used to compare the magnitude and placements of the limiting boundaries obtained by using full-span droop leading edges and full-span flaps. It can be seen from this figure and figure 6(b) that the full-span flap shifts the boundary to higher rates of descent and lower airspeeds.

The addition of the droop leading edge in conjunction with the full-span flap slightly decreased the region of objectionable buffet and slightly lowered the flight speed at which the limiting conditions occurred.

The characteristics exhibited by this aircraft at various airspeeds and rates of descent are thought to be similar to those which may be expected in other tilt-wing aircraft even though the magnitudes of the disturbances and the detailed flight conditions may be different. Methods of further alleviating these undesirable characteristics in future designs (objectionable buffet and stall limits) may be found through the use of a larger droop leading edge, slats or other leading-edge stall-alleviation devices, larger flap deflections, a different wing planform, boundary-layer control or blown flaps, and/or the use of an optimum ratio of wing chord to rotor diameter.

Control

<u>Hovering step inputs</u>.- Step pedal inputs were made during hovering flight with tail-yaw-fan control phased in and out. Figure 7(a) shows a typical time

history of a step pedal input in the hovering configuration with tail yaw fan out (yawing moment obtained solely by aileron action) and the resulting yawing angular velocity. Figure 7(b) shows a typical time history resulting from a step pedal input with both the tail-fan and full-span ailerons.

A compilation of the hovering control sensitivity and angular velocity damping is shown in figure 8. This figure shows the relation of tested values of sensitivity and angular velocity damping to the criteria for handling qualities given in reference 13. The shaded boundaries indicate minimum acceptable values of control sensitivity and angular velocity damping as set down in reference 13. It should be noted that the test points relate to the basic aircraft characteristics without any artificial damping being added. Figure 8(a) shows the yaw-control sensitivity of ailerons alone or tail yaw fan alone to be low relative to criteria values. The sensitivity and control power were found to be inadequate, particularly in ground effect where the aircraft experiences aircraft-induced disturbances. Out of ground effect the full-span ailerons gave about 60 percent more yaw-control moment than did the tail yaw fan. Figure 8(a) also shows the reduction of control in ground effect of about 25 percent, in keeping with results predicted by wind-tunnel data. The pilots, however, could not readily detect this difference. Ailerons alone did not provide sufficient control in or out of ground effect even under favorable operating conditions. The combined systems (full-span ailerons and yaw tail fan) gave adequate directional control for visual flight under light to moderate wind conditions (0 to 12 knots).

Roll angular-velocity damping and control were not affected by the addition of the full-span flaps. Since the roll-control sensitivity was previously found to be high (2.8 times as great as the minimum requirements of ref. 13), it was reduced to the value shown in figure 8(b). Pilots found that the decreased control sensitivity reduced the tendency to overcontrol laterally and resulted in lateral control sensitivity which was considered good.

Pilot's comments indicated that the total roll-control moment available was adequate but could not be reduced safely below the present value because occasionally, during hovering maneuvers near the ground and during recovery from large roll-control inputs, maximum roll control was required for an instant. It was felt that similar maneuvers might be performed in an operational aircraft.

The addition of full-span flaps did not affect control power, sensitivity, or damping in pitch. Figure 8(c) shows the relation of the VZ-2 pitch angular velocity damping and sensitivity to the criteria of reference 14. This relationship of sensitivity and damping were judged to be inadequate by the pilots as was the total control power near hover. Because of these characteristics, pilots were prone to overcontrol the aircraft throughout the transition range and cause pilot-induced oscillations. The longitudinal-stability augmentation system was beneficial in reducing pilot-induced oscillations up to 85 knots. At speeds above 85 knots, the augmentation-system characteristics were unsatisfactory and contributed to pilot-induced oscillations.

<u>Step inputs in the transition-flight configuration</u>.- Step yaw inputs were performed at discrete wing angles throughout the wing angle range with

tail-yaw-fan control full in and out and with aileron deflections in amounts as programed with wing tilt. Figure 9 shows typical time-history traces of a directional step displacement and the resulting yaw and roll angular velocities with the yaw tail fan out. Direct coupling between yaw and roll (fig. 9) caused by the deflection of the ailerons at a wing angle of 50° and flap deflection of 27° was barely noticeable to the pilots and was not objectionable. Pilots reported that coupling of rolling velocities due to a rudder pedal step input with this particular flap configuration was negligible in most of the flight regions tested; however, if an attempt is made to increase the flap size and/or deflection to give adequate control, excessive roll-yaw coupling may become a problem.

Figure 10 shows a plot of the variation of yaw angular acceleration per unit cockpit control displacement or control sensitivity with airspeed for the tail-yaw-fan—aileron combination and for ailerons alone. At 37 knots, figure 10 indicates the yaw-control power was near zero in left yaw. This dropoff in yaw-control power from hover to 37 knots is largely due to the aileron programing. Wind-tunnel results presented in reference 15 show that the aileron yaw effectiveness per degree aileron deflection remains essentially constant throughout the transition speed range except for a small amount of dropoff between 0 and 20 knots. These results suggest that higher aileron deflections with pedal throughout the transition speed range would have provided improved yaw control for the test aircraft.

Figure 11 shows the variation of yaw angular displacement per unit time, or response, with airspeed. From this figure it may be seen that the minimum criteria set by reference 13 is higher than the angular yaw displacements obtained at low forward speeds with the tail yaw fan out even though the basic aircraft damping is lower than specified in the criteria. Yaw angular response in hovering with the tail yaw fan functioning is well above the minimum set by references 13 and 14. The criteria of references 13 and 14, however, call for considerably higher levels of damping than were present in this case. When the ailerons alone were used, the yaw-control response was judged by pilots to be totally inadequate in transition flight. When the ailerons were used in conjunction with the tail fan for yaw control, the response characteristics were judged by the pilots to be satisfactory only for limited study of STOL operations.

Figure 12 shows a time history of the angular velocity response to the step input for the near-zero response case. The fact that the yaw angular velocity is gradually increasing is attributed to the directional instability at this airspeed.

Roll-control sensitivity is shown plotted against airspeed in figure 13. Pilots reported that roll-control sensitivity, as shown in figure 13, and the total control power were adequate for all maneuvers investigated or envisaged throughout the speed range. Roll response remains essentially constant with airspeed as is shown in figure 14. Figure 15 shows a typical time history of a roll step input and the resulting roll angular velocity. The roll angular velocity in this figure was obtained by using a roll-reversal or "false start" technique to minimize sideslip at the time of maximum roll rate and to obtain a high roll rate within a reasonable angular roll displacement from level.

Trim change with airspeed.- The variation of longitudinal stick position with trim-level-flight airspeed is shown in figure 16. Two conditions are compared in this figure. The solid line represents the trim position obtained from the basic aircraft wing without full-span flaps whereas the dashed line is for the aircraft with programed full-span flaps. Data for both curves were obtained from flight where the fuselage attitude was held at a constant angle of 0°. The figure shows that the programed full-span flap on the aircraft is beneficial in reducing the longitudinal pitching moment and its variation throughout the speed range. The case with the wing flap as programed requires only ±10 percent longitudinal stick position variation with trim throughout the transition whereas the unflapped wing required a maximum of 30 percent forward stick.

Trim change with power.- Very little trim change with power was noted for the flapped wing; however, data for the lower wing angles showed that as power was decreased and the airspeed was held constant, the longitudinal stick trim moved aft. Total trim change from high power flight to limiting rate of descent was approximately 10 percent of the total travel.

Effect of the Flap on Operating and Performance Characteristics

The effect of the full-span flap on the variation of wing angle and power required with trim-level-flight airspeed throughout the transition speed range is shown in figures 17 and 18. Figure 17 is a plot of the variations of wing angle of attack with trim-level-flight airspeed at several combinations of wing-flap deflections where the wing with flap and the basic wing (without flap) are compared. Figure 18 is a plot of the variation of engine shaft horsepower with trim-level-flight airspeed and also compares the basic wing and the flapped wing.

In figure 17 it is shown that at speeds below 40 knots the wing with flap displays a steep wing-angle—airspeed gradient resulting in small changes in airspeed with a given wing angle change. It should be mentioned here that there is a steep dropoff in power in the same speed range. At lower wing incidences where the full-span flap is retracting, a given wing-angle change represents a large speed change. The programed flap schedule with incidence provided easy transition from hovering into forward flight up to approximately 40 knots. In this aircraft, the power, which was controlled by the engine fuel control governor, tended to fall off with increasing forward speed. As the flaps began to retract, therefore, the loss in lift, the tendency to lose horsepower, and the consequent lack of adequate acceleration of the aircraft required caution in completing the transition to airplane flight.

Since, as discussed in the next section, losses in lift occurred below 40 knots in the presence of the ground for this aircraft with large flap deflections, it would seem desirable from a handling-qualities standpoint to reduce the flap deflection to lower values at the higher wing angles. These two considerations (loss in lift in the presence of the ground at low speeds and the tendency to settle out near the end of the conversion) suggest a better flap schedule for use with this aircraft as indicated in figure 19. It should be noted here that the flap angle should be automatically programed with wing tilt in order to minimize pilot workload during transition. The most desirable flap programing schedule for this airplane is not known but the type of programing suggested in figure 19 would have provided a better starting point than a more arbitrary relation. The ultimate choice of flap programing is a compromise between handling qualities and performance.

In general, figure 18 shows that at level-flight transition airspeeds, the power required is less for a flapped wing. In fact, the effect of the flap is even greater than indicated since the modified configuration is 200 pounds heavier than the original configuration. The added weight partially explains the greater power required by the flapped-wing aircraft below 18 knots. The power-required curve of the aircraft with flap would, of course, be different with the assumed flap programing of figure 19. Comparison of tuft photographs (not presented) from the flapped and unflapped wing indicates that the reduced amount of flow separation on the flapped wing contributed to the reduction in the power required during transition.

Effect of Ground Proximity on STOL Characteristics

The results of reference 16 indicate a more detrimental ground effect (loss of lift or increase in power required) for tilt-wing configurations with flaps than with a plain wing below 30 knots. At speeds above 30 knots, the power requirements for the flapped tilt-wing model were lower than those for the plain tilt-wing configuration. Operationally, the seriousness of the problems that could arise with regard to this loss-of-lift phenomenon during landing approaches depends upon whether there is excess power available or whether it occurs too rapidly for the pilot and/or aircraft to respond quickly enough to correct a dangerous rate of sink. After the full-span flap was added to the VZ-2, an investigation was made to study these effects in flight. Steady approaches to landings were made at wing incidence angles of 30°, 40°, 50°, 60°, and 70°, with the flap deflected in accordance with figure 4. The fuselage attitude was held approximately in landing attitude. Typical time histories of these steady landing approaches showing the resulting normal and longitudinal accelerations for each of the wing incidence angles are presented in figure 20. The normal acceleration is integrated to give the vertical-velocity increment. If the normal acceleration falls below 1 g as is the case at the higher wing angles, the vertical velocity is increasing. It should be noted here that the pilot made no attempt to arrest the increased rate of sink during the tests for these measurements.

The time histories of the landings for incidence angles of 30° and 40° are shown in figures 20(a) and 20(b). The pilot commented that the ground effect was actually favorable in these configurations in that the aircraft floated from a landing approach. At wing incidence angles of 60° and 70° during steady landing approaches, the pilot reported that the rate of descent "picked up markedly" within 10 feet of the ground and a moderate nose-down trim change occurred, for which the pilot attempted to correct. The rate of sink increased up to a maximum of about $3\frac{1}{2}$ feet per second according to the data. The time histories of these landings are shown in figures 20(d) and 20(e). For the landings made at 50° wing incidence angle, the pilot reported characteristics similar to those at incidence angles of 60° and 70°; however, at this angle (50°) both sink rates and trim changes were reduced in magnitude. A time history of this landing is shown in figure 20(c). These general trends confirm the results of reference 16. The pilot commented that under normal operating conditions the increased rate of sink could be easily controlled with the power available. Pilots also commented that the nose-down trim change could be controlled. The increased rate of sink might be more difficult to control during operations under overload conditions, in rough air, or during instrument landings.

Negative ground effect is plotted against speed as shown in figure 21. The data for this figure are derived from figure 20 and other similar data. This figure shows that at the higher approach speeds (lower wing angles) there is no rate-of-descent increment from the steady-state glide angle; however, as the wing angle is increased, the rate-of-descent increment approaches $3\frac{1}{2}$ feet per second.

The importance of negative ground effect on take-off performance has been demonstrated by the fact that the power required in ground effect with flaps deflected is greater than out of ground effect. The pilot noted when lifting off at wing angles of 60° (V = 23 knots) and 70° (V = 19 knots) that the attitude of the aircraft was not held as easily as desired because the net moment on the aircraft due to the landing gear and flap nose-down moment changed direction rapidly as lift-off was approached. When the aircraft climbed out to about a 10-foot altitude at constant power, the pilot reported a large nose-up trim change accompanied by an increase in lift referred to by the pilot as "ballooning." Figure 22 shows a time history of longitudinal stick position and horsepower during the take-off and climb at a wing incidence angle of 62° and a corresponding flap setting of 26°. In this case the pilot was attempting to maintain a longitudinal attitude consistent with that of the previously discussed landing approaches. When the pilot held the longitudinal control fixed after take-off, the aircraft assumed a much steeper nose-up attitude when passing through a height of approximately 10 feet, and a zoom in rate of climb and altitude resulted. At wing incidences of 50° and lower, the pilot did not experience the strong trim change or ballooning tendencies.

CONCLUSIONS

The results of a flight investigation on the modified VZ-2 tilt-wing VTOL research aircraft indicate the following conclusions:

1. The rate-of-descent capability was substantially improved by the addition of a full-span flap, even though the maximum flap deflection was only 30°. The high-speed limiting boundary was not as sharply defined with the flapped wing as with the basic wing. The low-speed end of the boundaries for both the flapped and unflapped configurations was defined by approximately the same static directional instability and lack of sufficient directional control to cope with the instability and directional disturbances.

2. Yaw control in hovering as provided solely by the deflection of the full-span ailerons was found to be marginal even for favorable conditions, particularly in ground effect, because the basic aircraft had self-induced disturbances close to the ground. When the ailerons were used in hovering to supplement the yaw fan, the overall yaw-control power was considered operationally adequate for visual flight. In the low-speed transition region, the ailerons alone were totally inadequate.

3. A reduction in roll-control sensitivity and control power from that of the original configuration in the hovering and low-speed range (0 to 25 knots) resulted in control characteristics throughout the transition speed range which were considered more satisfactory by pilots. These results tended to confirm the conclusions indicated by variable-stability helicopter results. Although the total roll-control moment was considered by pilots to be adequate, random aircraft disturbances during hovering maneuvers in ground effect sometimes required all the roll control available for an instant.

4. During steady landing approaches at high wing angles (60° and 70°), the rate of descent increased markedly within about 10 feet of the ground and resulted in increases in rates of descent of $3\frac{1}{2}$ feet/sec for these tests. The pilot indicated that the increased rate of sink could easily be prevented with a power increase under flight-test conditions. The increased rate of sink might, however, be more difficult to control during operations under overload conditions, in rough air, or during instrument landings. The negative ground effect may prove to be more serious for some take-off conditions.

5. During take-offs at wing incidence angles of 60° to 70°, there was a rapid and large nose-up trim change when the aircraft was approximately 10 feet off the ground. The concurrent increase in lift caused pronounced ballooning. The large trim change was considered undesirable by the pilots.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., December 2, 1964.

REFERENCES

1. Newsom, William A., Jr.; and Tosti, Louis P.: Force-Test Investigation of the Stability and Control Characteristics of a 1/4-Scale Model of a Tilt-Wing Vertical-Take-Off-and-Landing Aircraft. NASA MEMO 11-3-58L, 1959.

2. Tosti, Louis P.: Flight Investigation of the Stability and Control Characteristics of a 1/4-Scale Model of a Tilt-Wing Vertical-Take-Off-and-Landing Aircraft. NASA MEMO 11-4-58L, 1959.

3. Tosti, Louis P.: Aerodynamic Characteristics of a 1/4-Scale Model of a Tilt-Wing VTOL Aircraft at High Angles of Wing Incidence. NASA TN D-390, 1960.

4. Tosti, Louis P.: Rapid-Transition Tests of a 1/4-Scale Model of the VZ-2 Tilt-Wing Aircraft. NASA TN D-946, 1961.

5. Tosti, Louis P.: Longitudinal Stability and Control of a Tilt-Wing VTOL Aircraft Model With Rigid and Flapping Propeller Blades. NASA TN D-1365, 1962.

6. Thomas, Lovic P., III: A Flight Study of the Conversion Maneuver of a Tilt-Wing VTOL Aircraft. NASA TN D-153, 1959.

7. Pegg, Robert J.: Damage Incurred on a Tilt-Wing Multipropeller VTOL/STOL Aircraft Operating Over a Level, Gravel-Covered Surface. NASA TN D-535, 1960.

8. Ward, John F.: Structural-Loads Surveys on Two Tilt-Wing VTOL Configurations. NASA TN D-729, 1961.

9. Reeder, John P.: Handling Qualities Experience with Several VTOL Research Aircraft. NASA TN D-735, 1961.

10. Pegg, Robert J.: Flight-Test Investigation of Ailerons as a Source of Yaw Control on the VZ-2 Tilt-Wing Aircraft. NASA TN D-1375, 1962.

11. Pegg, Robert J.: Summary of Flight-Test Results of the VZ-2 Tilt-Wing Aircraft. NASA TN D-989, 1962.

12. Reeder, John P.: The Impact of V/STOL Aircraft on Instrument Weather Operations. Presented at the AGARD Flight Mechanics Panel Meeting on "All-Weather Operation" (Munich, Germany), Oct. 12-14, 1964.

13. Anon.: Recommendations for V/STOL Handling Qualities, AGARD, Rept. 408, Oct. 1962.

14. Anon.: Helicopter Flying and Ground Handling Qualities; General Requirements for Military Specification MIL-H-8501A, Sept. 7, 1961, Amendment 1, Apr. 3, 1962.

15. Kirby, Robert H.; Schade, Robert O.; and Tosti, Louis P.: Force-Test Investigation of a 1/4-Scale Model of the Modified VZ-2 Aircraft. NASA TN D-2382, 1964.

16. Kuhn, Richard E.; and Hayes, William C., Jr.: Wind-Tunnel Investigation of Longitudinal Aerodynamic Characteristics of Three Propeller-Driven VTOL Configurations in the Transition Speed Range, Including the Effects of Ground Proximity. NASA TN D-55, 1960.

TABLE I.- PHYSICAL CHARACTERISTICS OF THE VZ-2 AIRCRAFT

Rotors:	
Diameter, ft	9.67
Blade chord, in.	13.00
Blade twist (linear, root to tip), deg	19.2
Airfoil section	NACA 0009 with 0.5-inch cusp
Blade taper ratio	1
Solidity, $bc/\pi R$	0.22
Distance between rotor axes, ft	14.67
Differential pitch, deg	±3
Normal operating speed, rpm	1,416
Wing:	
Span (excluding tips), ft	24.88
Chord, ft	5.25
Chord, flap extended, ft	5.66
Airfoil section	NACA 4415
Taper ratio	1
Sweep, deg	0
Dihedral, deg	0
Pivot, percent chord	33.5
Ailerons:	
Chord, ft	1.20
Span, ft	10.30
Tilt range (referenced to upper longeron), deg	9 to 85
Flaps:	
Type	Single slotted
Total area, sq ft	18.65
Total chord, ft	1.81
Total span, ft	10.30
Maximum deflection, deg	30
Maximum extension, in.	4
Vertical tail:	
Height, ft	5.43
Chord, mean geometric, ft	5.90
Sweep at leading edge, deg	28
Basic airfoil section	NACA 0012
Rudder:	
Chord, in.	21.5
Span, in.	58.0
Horizontal tail:	
Span (less tips), ft	9.90
Chord, ft	3.00
Sweep, deg	0

TABLE I.- PHYSICAL CHARACTERISTICS OF THE VZ-2 AIRCRAFT - Concluded

Taper ratio	1
Airfoil section	NACA 0012
Dihedral, deg	0
Length (distance from wing pivot to leading edge of tail), ft	10.475
Hinge point (distance from leading edge), in.	8.3
Pitch and yaw control fans:	
Diameter (both fans), ft	2.00
Moment arm about wing pivot (both fans), ft	12.35
Number of blades	4
Speed, rpm	5,850
Fuselage length	26 feet 5 inches
Engine	850 hp gas turbine
Weight as flown with ejection seat, lb	3,730
Center of gravity, inches forward of wing hinge	0.4
Inertias:	
I_X, slug-ft^2	1,800
I_Y, slug-ft^2	3,450
I_Z, slug-ft^2	4,350
Total control travels:	
Lateral stick, in.	$9\frac{1}{8}$
Longitudinal stick, in.	$11\frac{1}{8}$
Pedal, in.	6

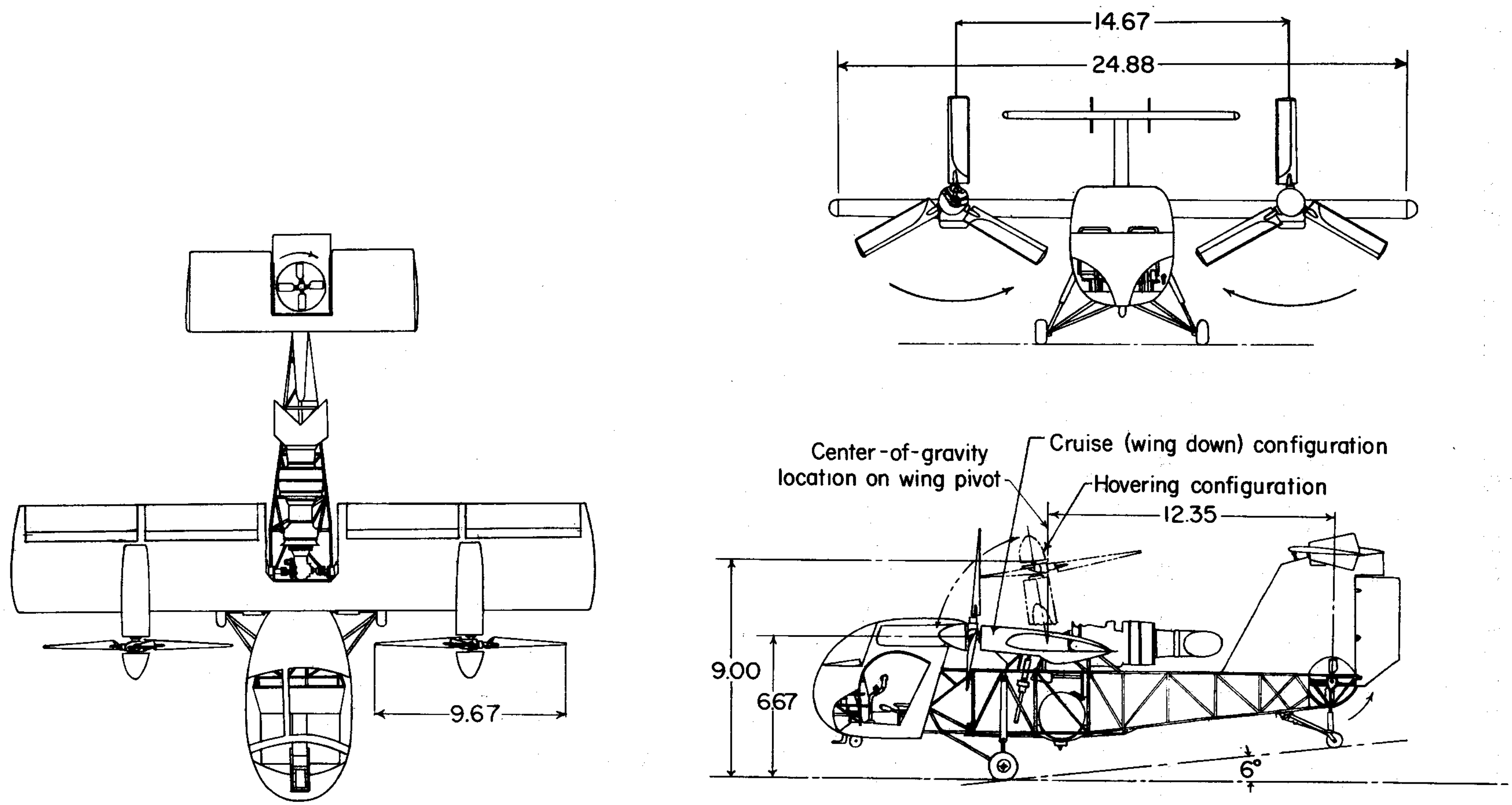


Figure 1.- Sketch of the tilt-wing VTOL aircraft. All dimensions are in feet unless otherwise specified.

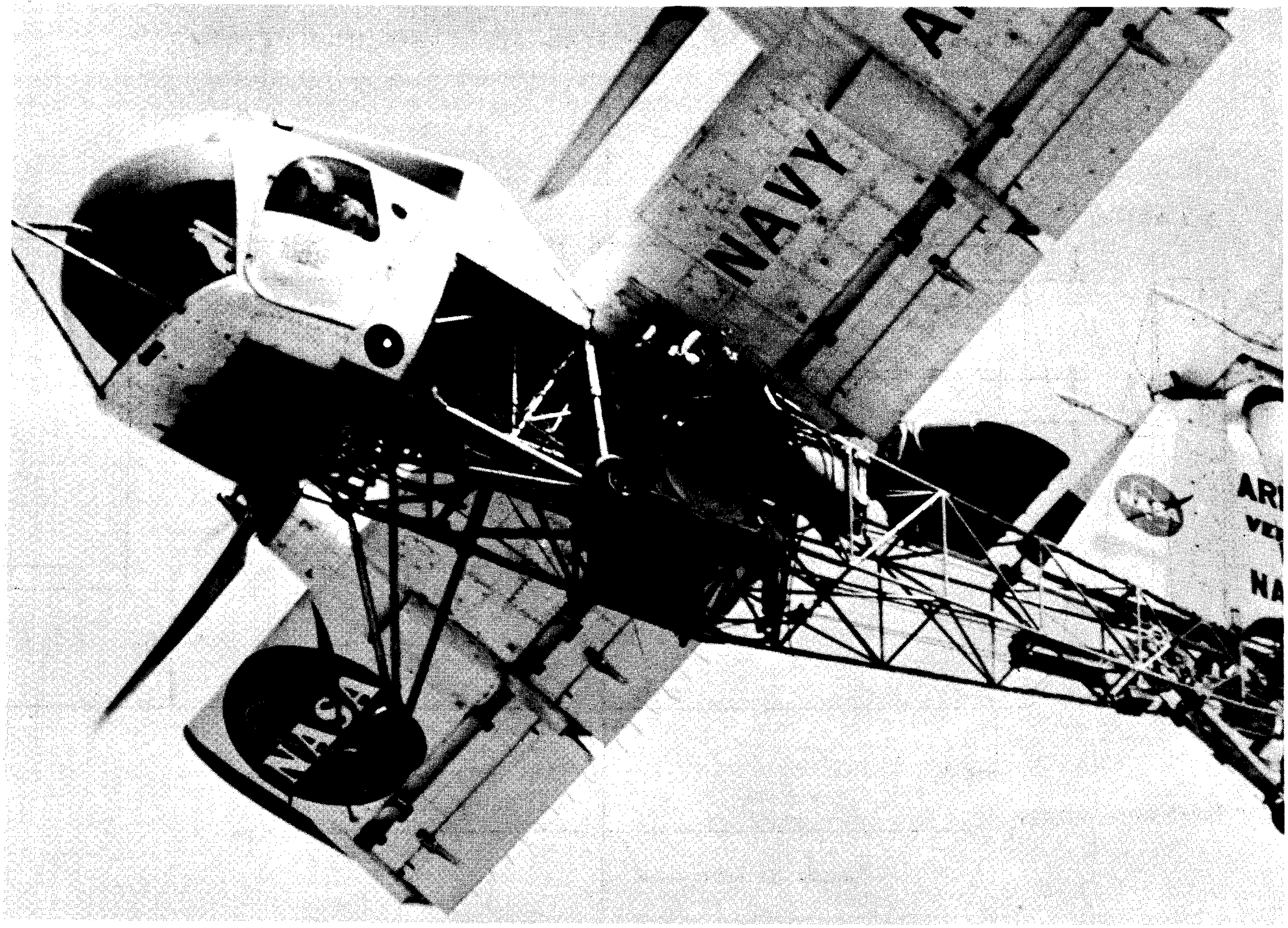


Figure 2.- Test aircraft in transition flight. L-63-5143

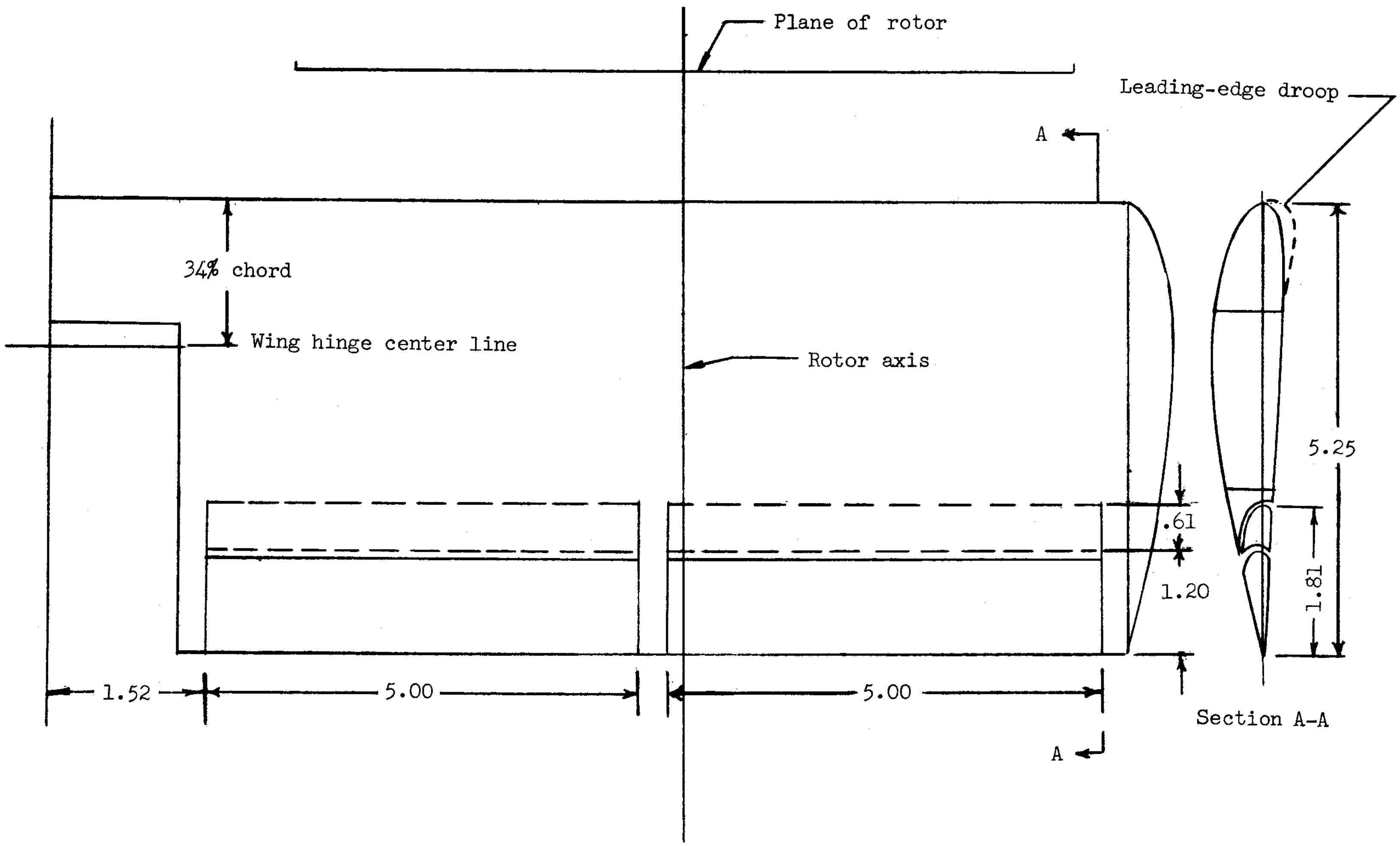


Figure 3.- Detail sketch of wing with full-span flap. (All dimensions are in feet.)

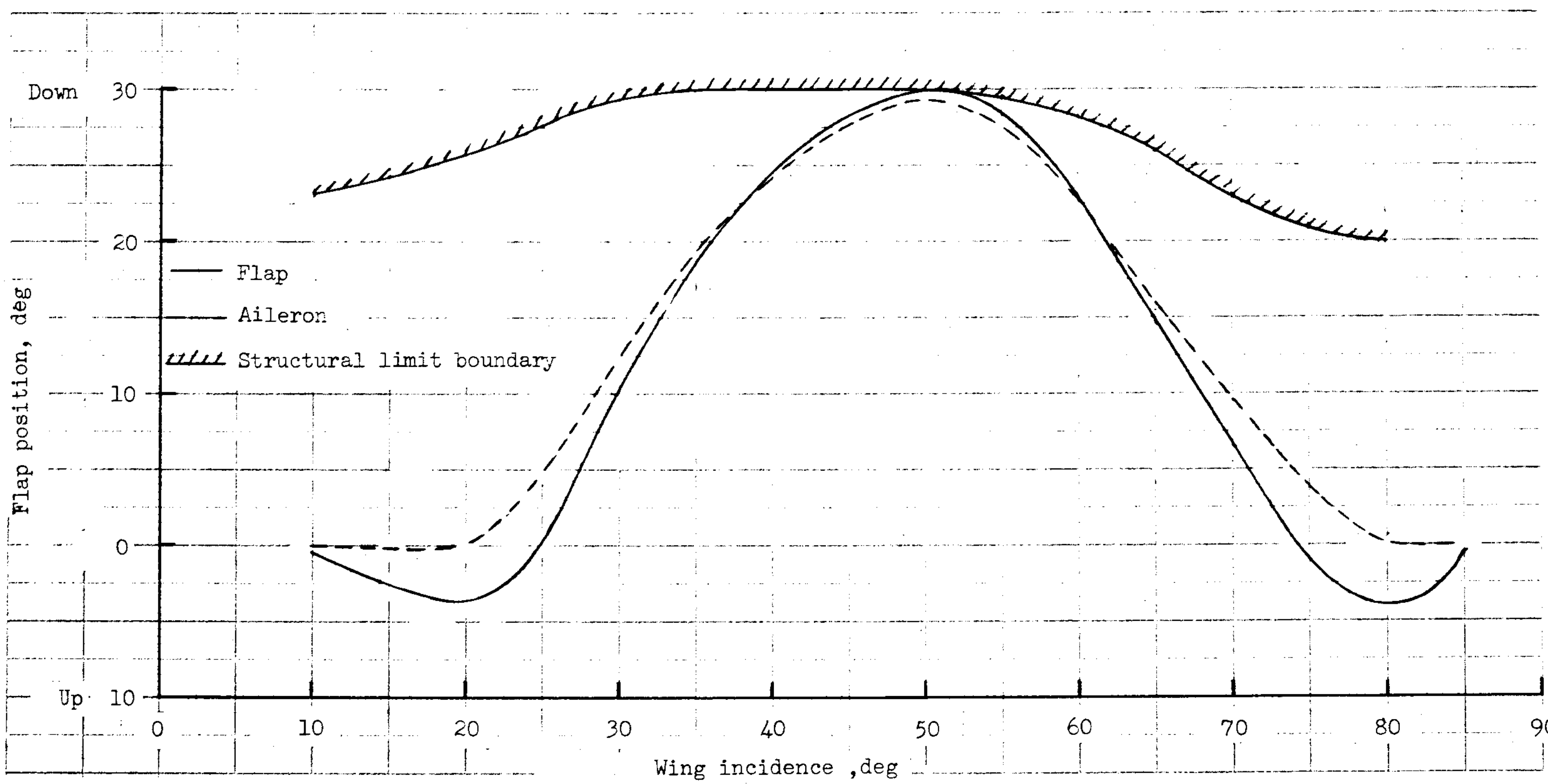
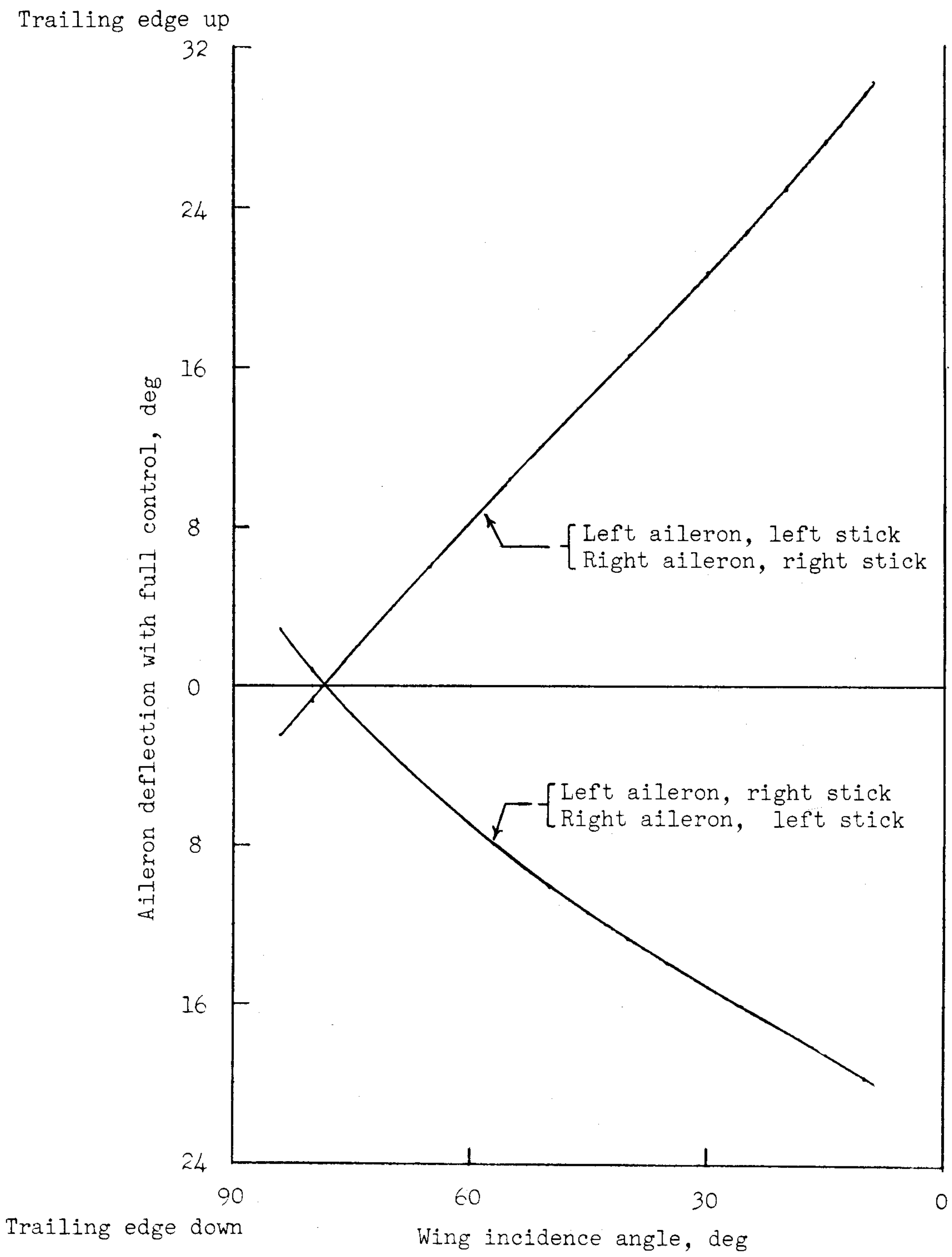
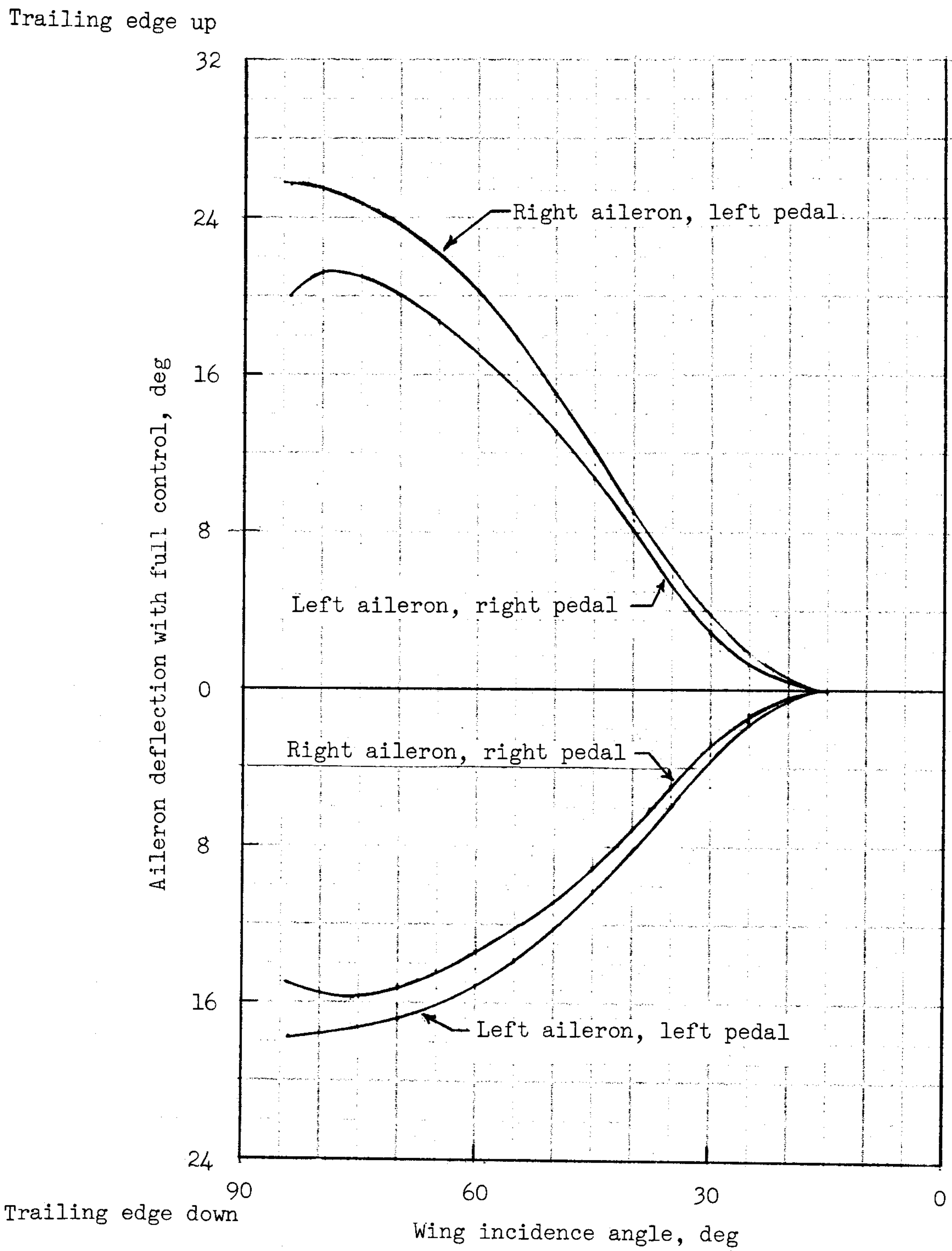


Figure 4.- Trailing-edge flap program with wing incidence angle when actuated by cam.



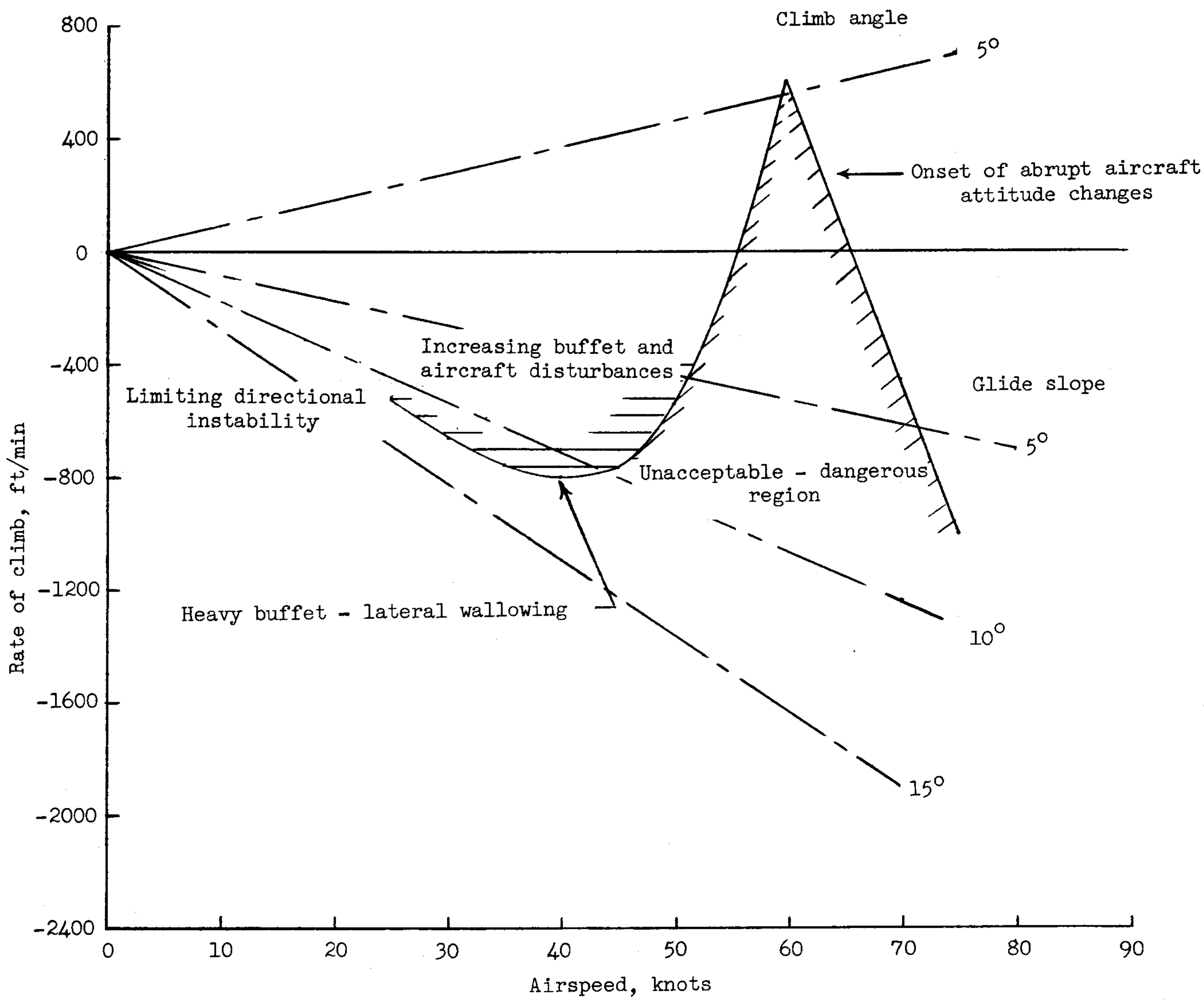
(a) Aileron deflection with full lateral stick.

Figure 5.- Aileron programing with wing incidence angle.



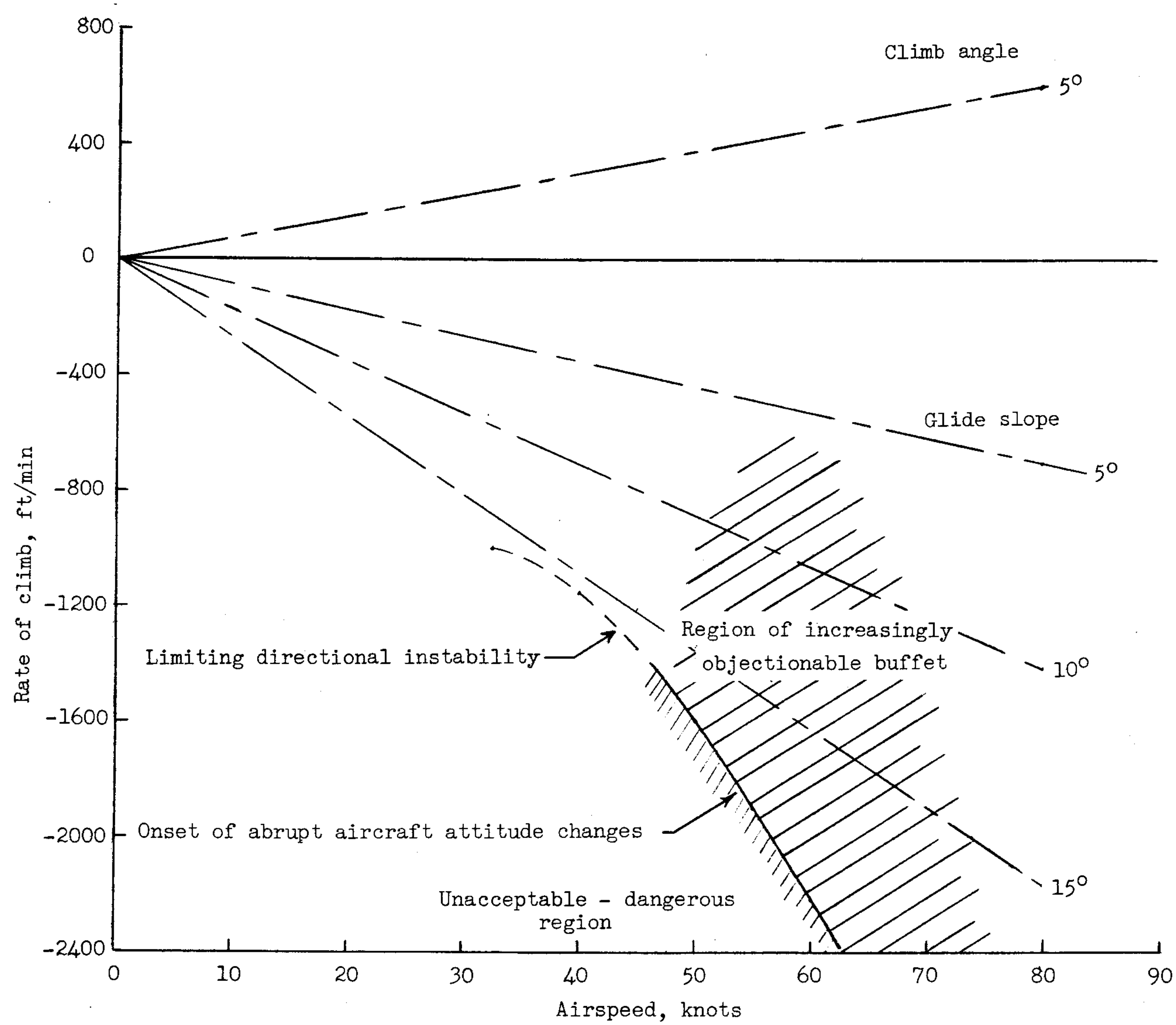
(b) Aileron deflection with full rudder pedal.

Figure 5.- Concluded.



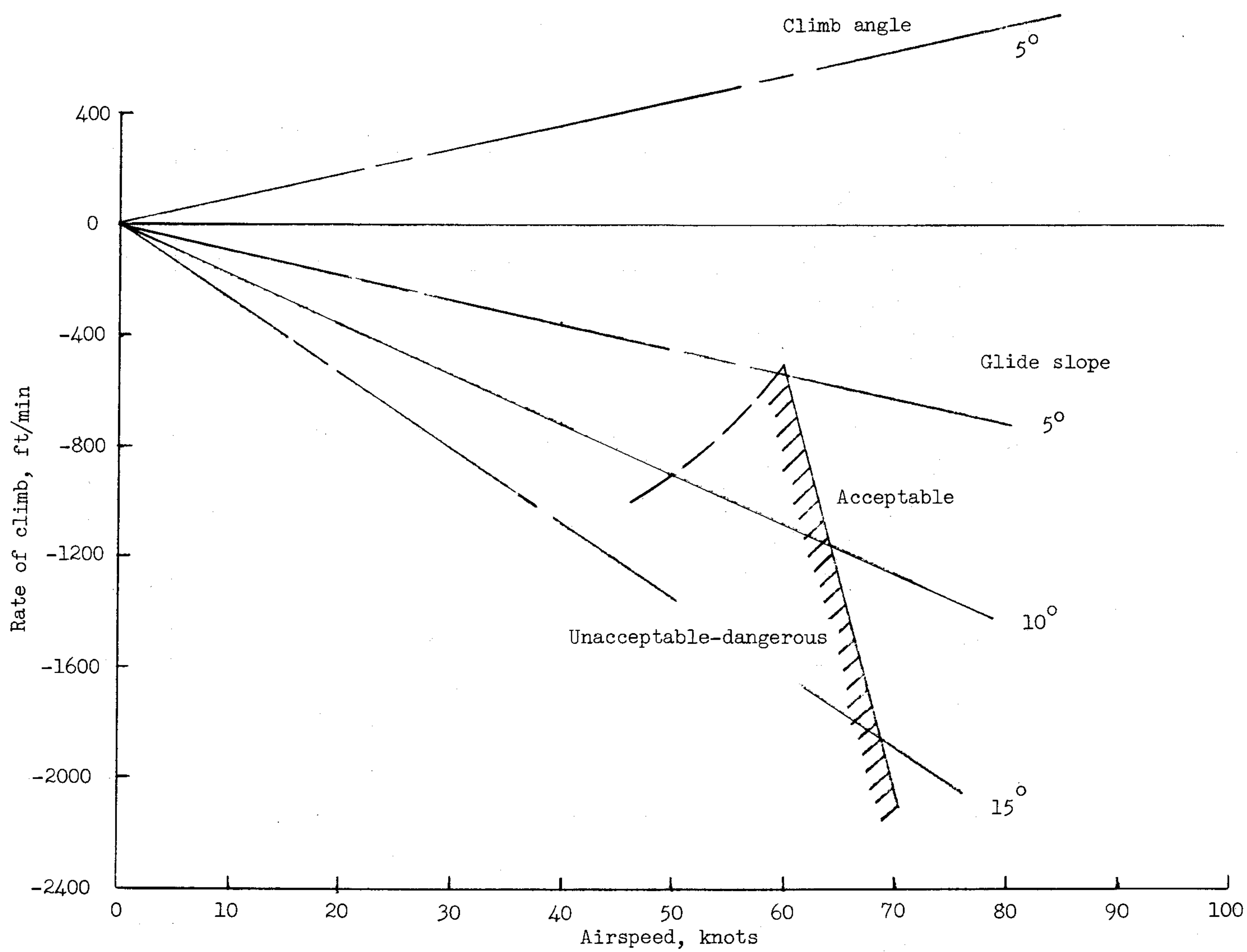
(a) Original wing without flap.

Figure 6.- Rate-of-descent boundaries.



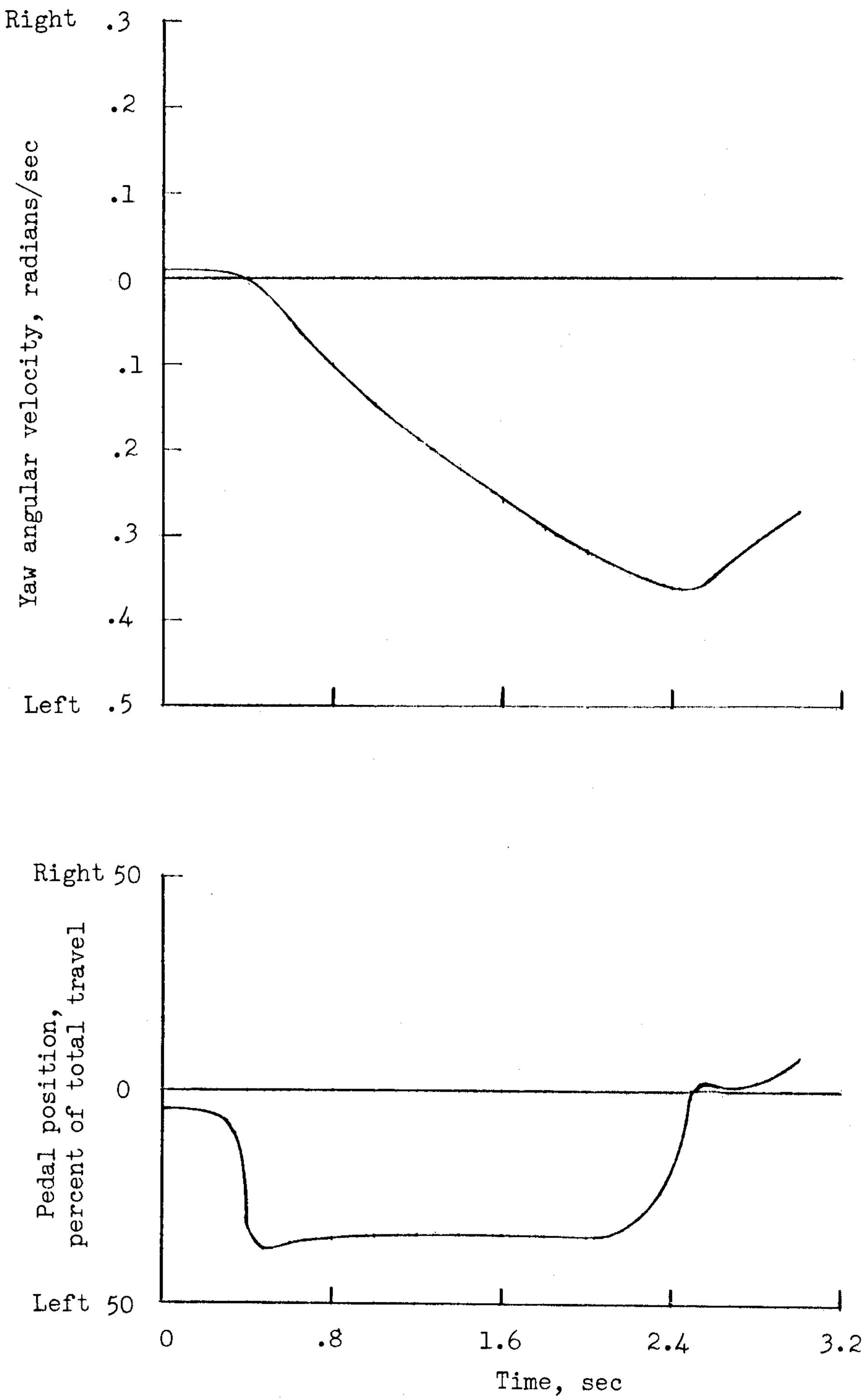
(b) Wing with single slotted flap.

Figure 6.- Continued.



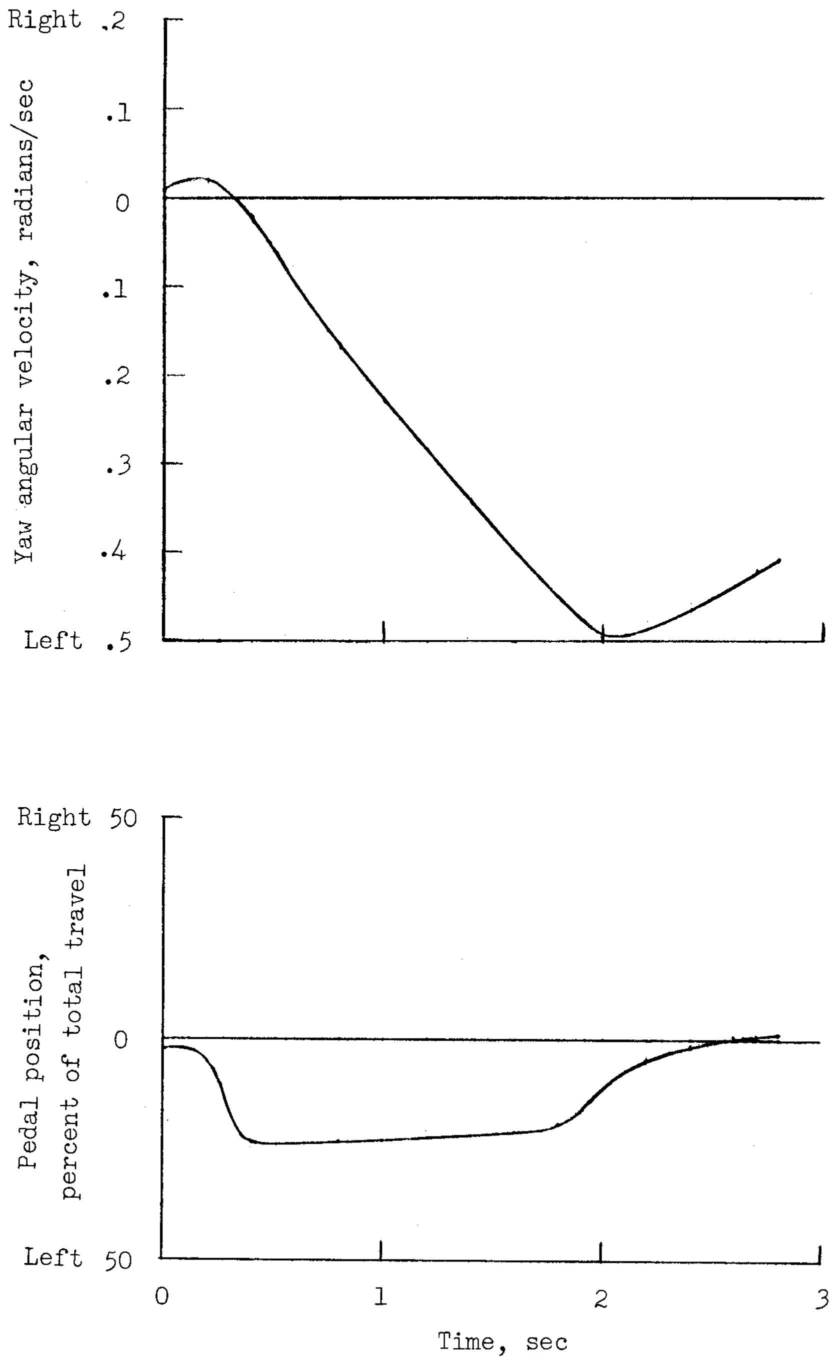
(c) Wing with full-span droop leading edge (from ref. 11).

Figure 6.- Concluded.



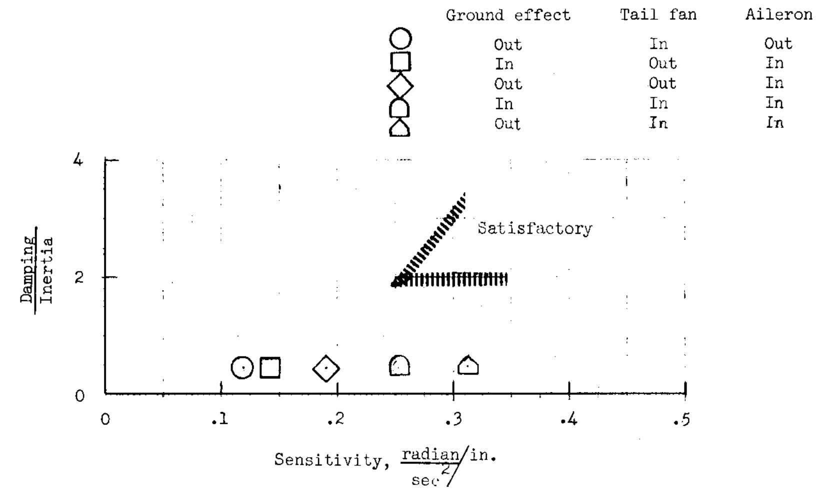
(a) Ailerons only; conditions: Yaw tail fan out; $i_w = 76^\circ$; $\delta_f = 18^\circ$; $V = 8$ knots; and $P = 772$ hp.

Figure 7.- Typical time history of a step pedal input and resulting yawing angular velocity.

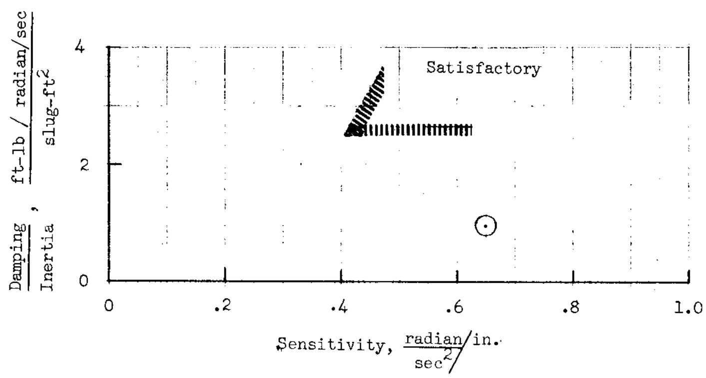


(b) Yaw tail fan plus ailerons. Conditions: Yaw tail fan in plus ailerons; $i_w = 76^\circ$; $\delta_f = 18^\circ$; V = 8 knots; and P = 772 hp.

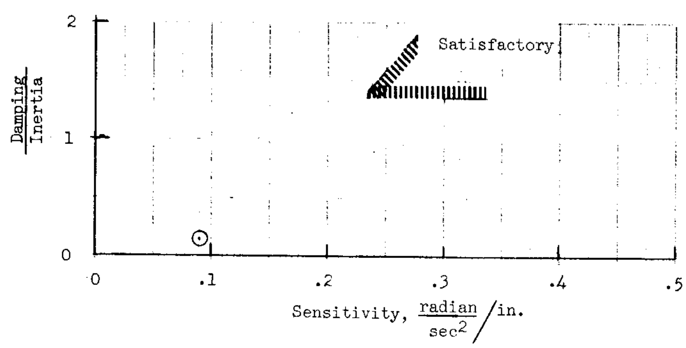
Figure 7.- Concluded.



(a) Yaw axis.



(b) Roll axis.



(c) Pitch axis.

Figure 8.- Comparison of control characteristics with minimum satisfactory control sensitivity and angular velocity damping boundaries as set forth by reference 13 for a 3,500-pound aircraft in hovering flight.

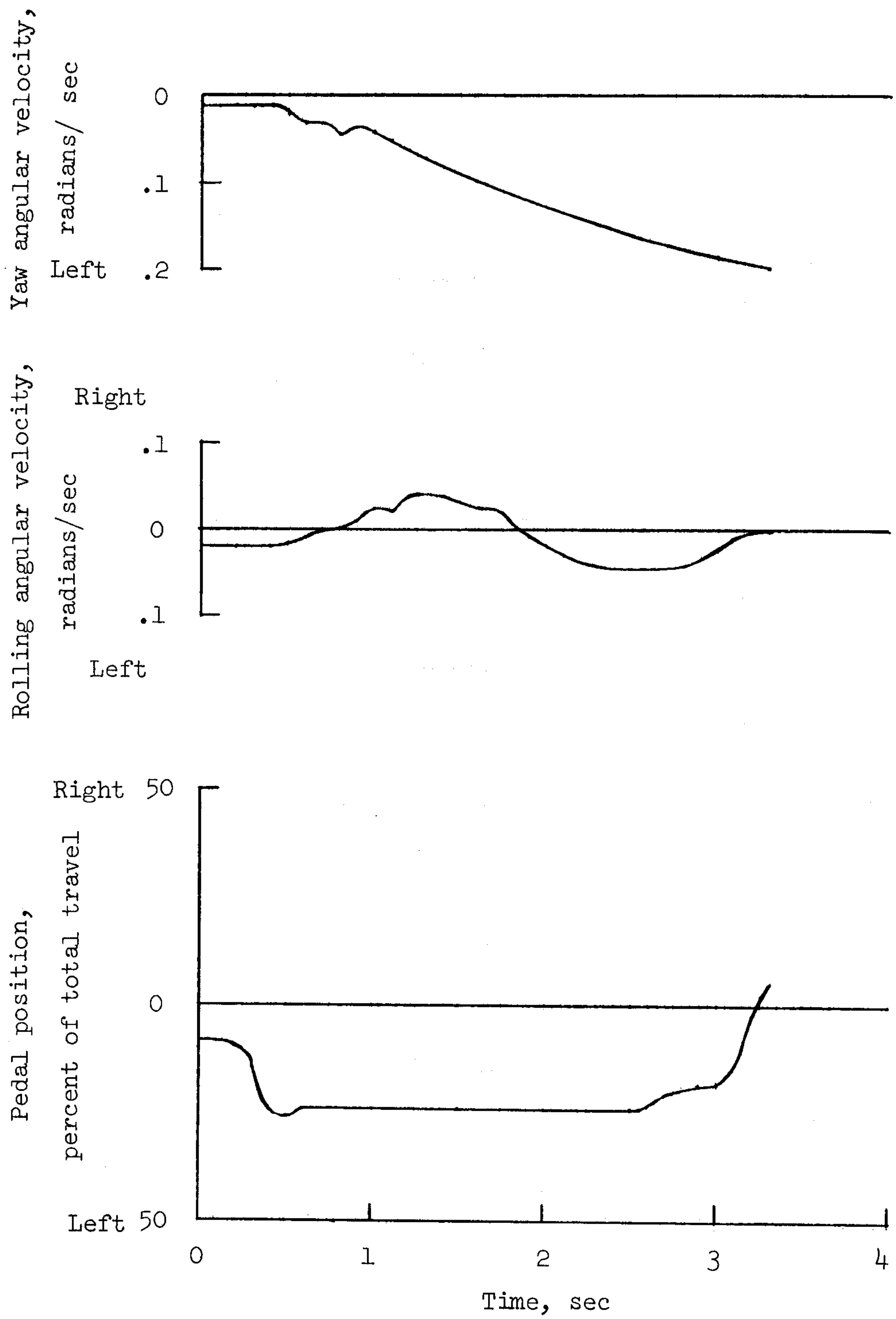


Figure 9.- Typical time history of directional input and the resulting lateral and directional angular velocities. $i_w = 50^\circ$; $\delta_f = 27^\circ$; $V = 25$ knots; and $P = 525$ hp. Yaw tail fan out.

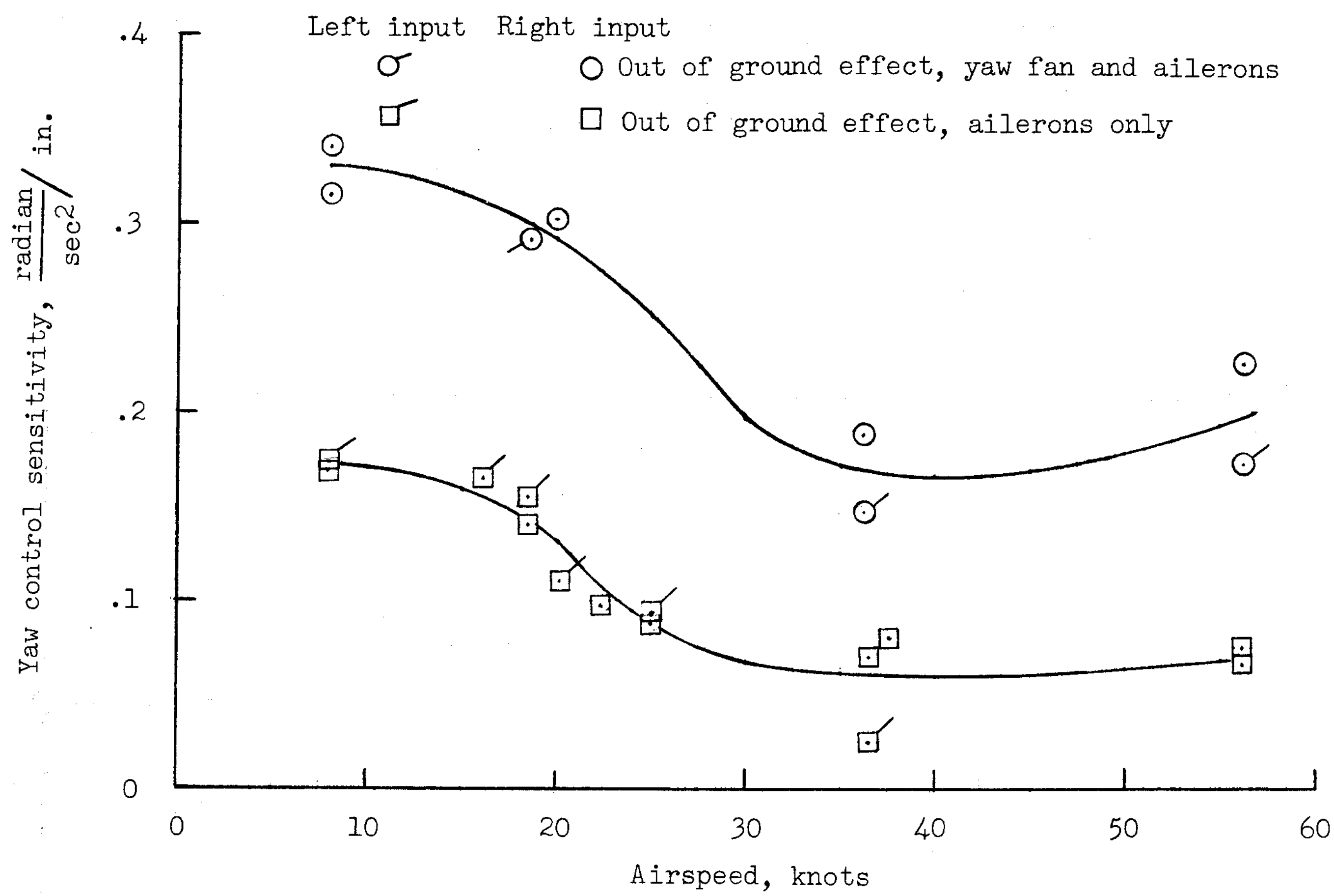


Figure 10.- Variation in yaw-control sensitivity with airspeed.

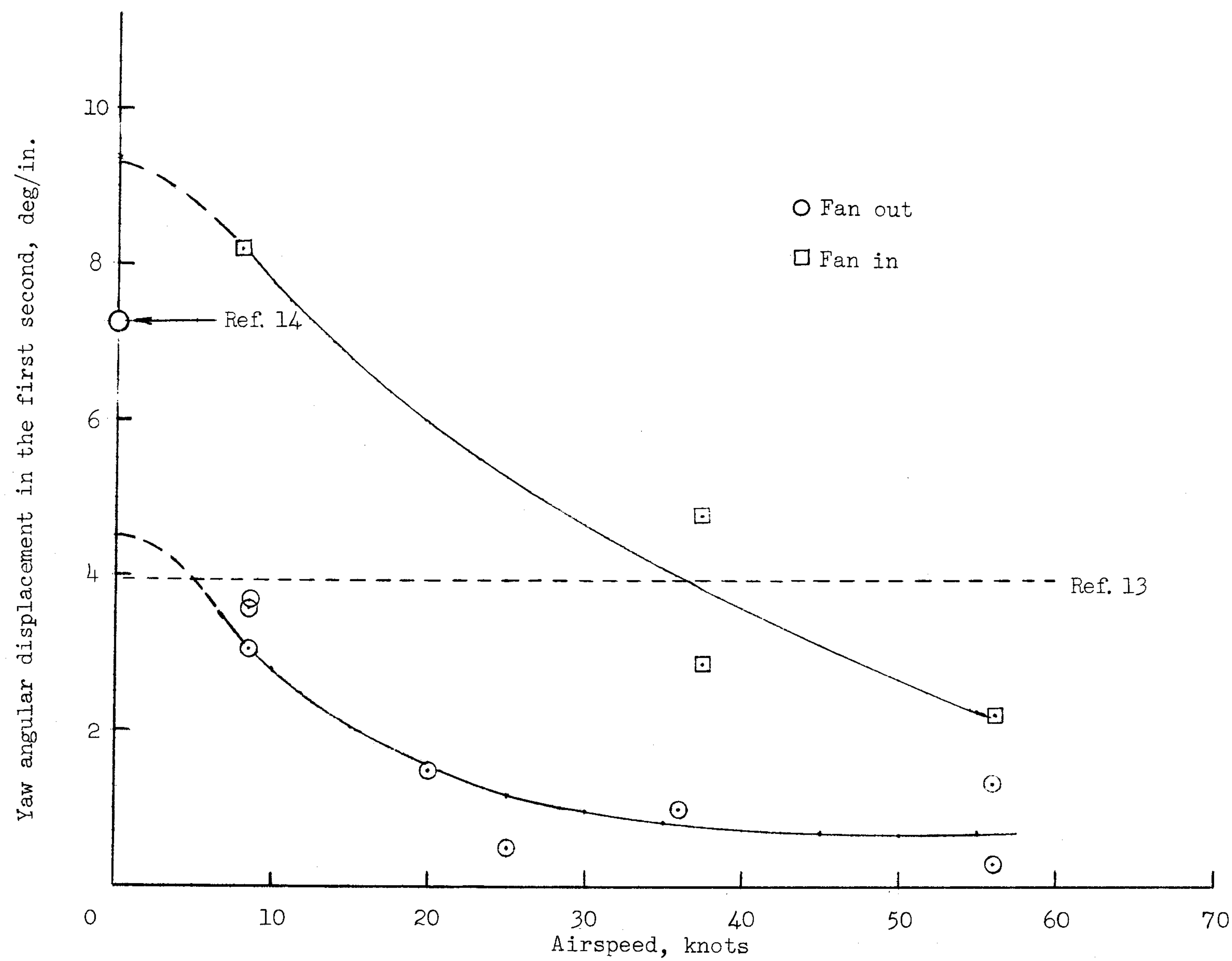


Figure 11.- Variation of yaw angular response per inch of pedal deflection with speed. Full-span aileron movement was expressed as a ratio in accordance with schedule in figure 5.

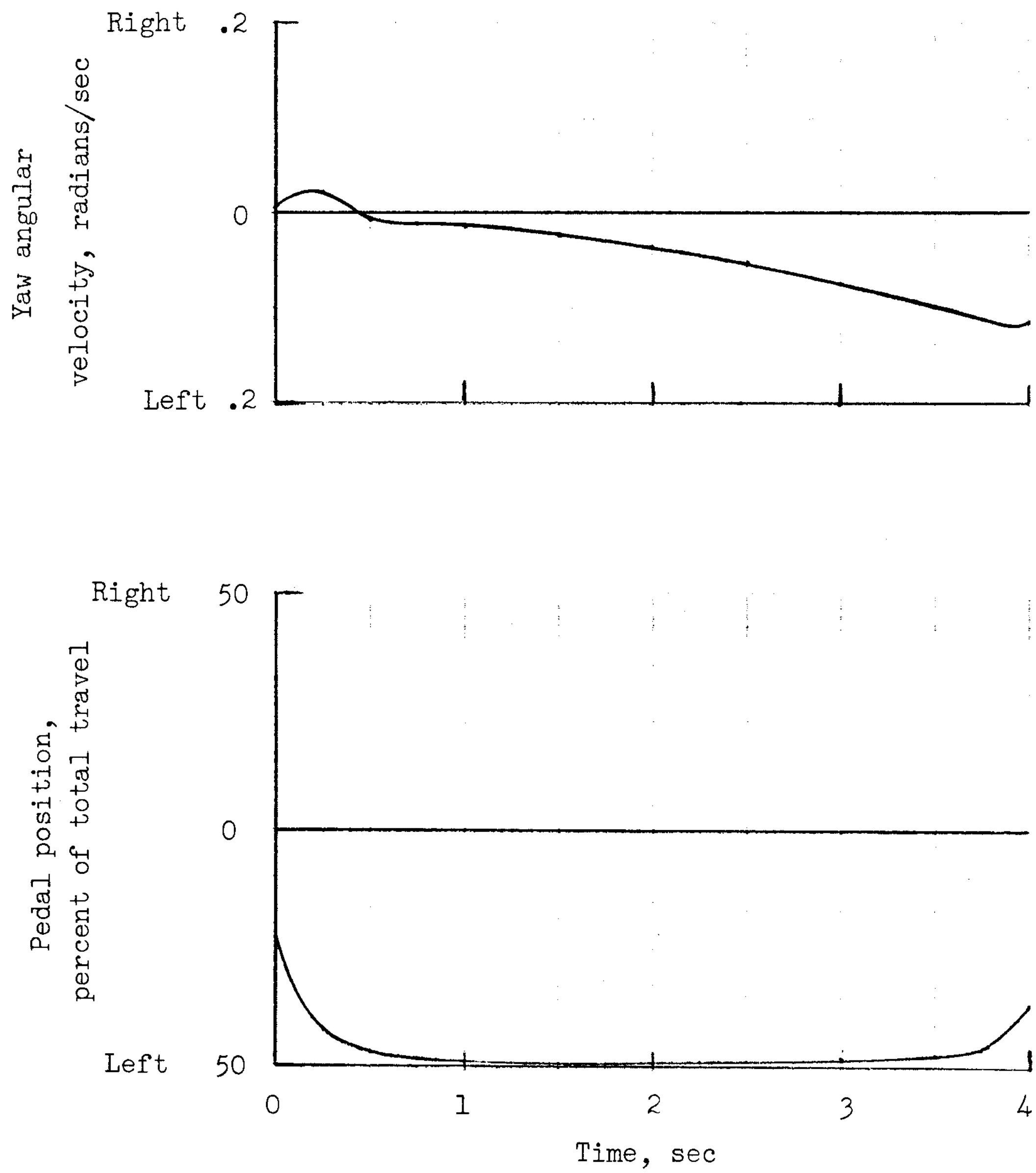


Figure 12.- Time history of directional step input to the left showing the near-zero response when using ailerons only (yaw fan out). $i_w = 37.5^\circ$; $\delta_f = 22^\circ$; V = 36.4 knots; and P = 390 hp.

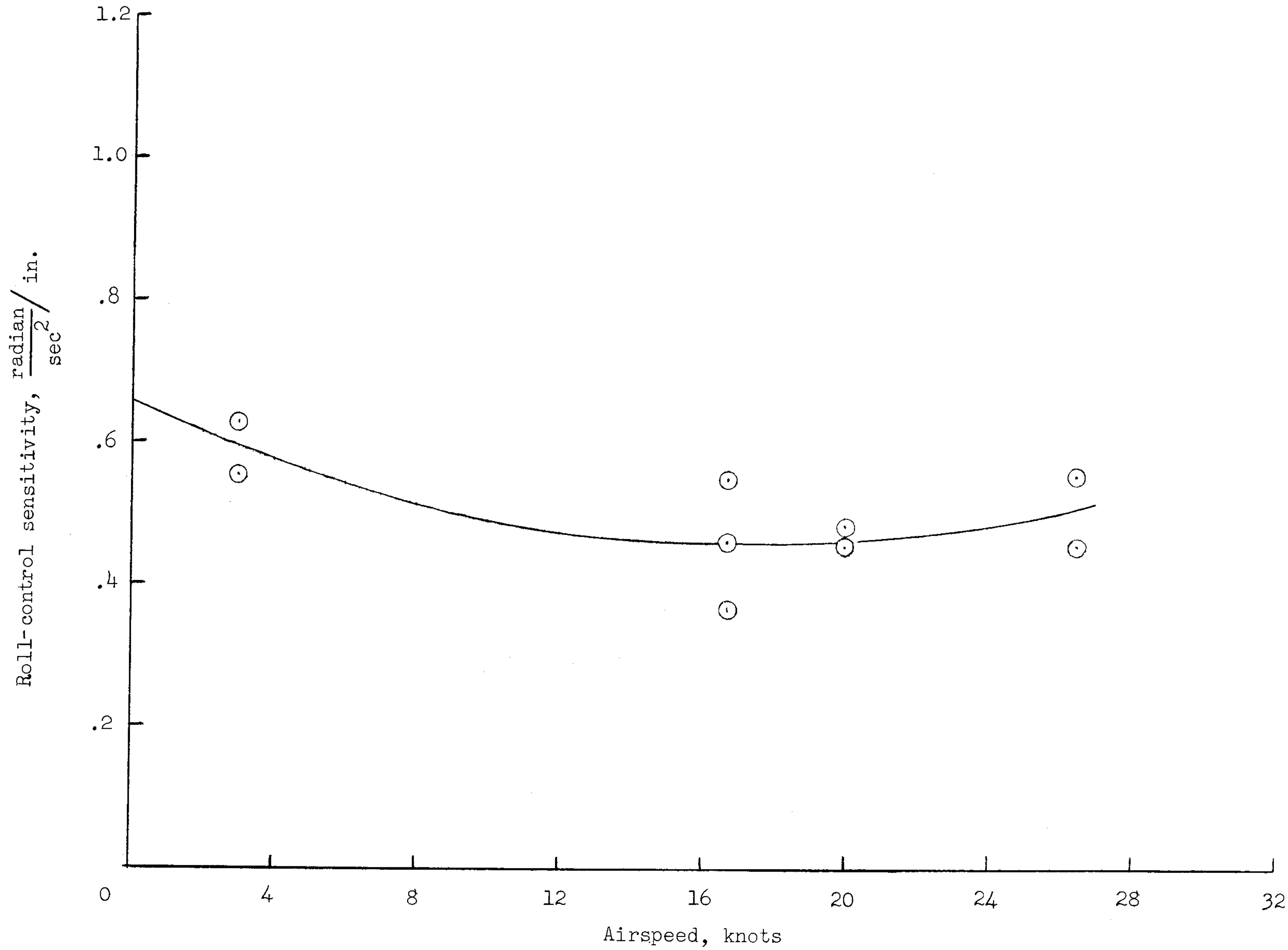


Figure 13.- Variation of roll-control sensitivity with airspeed.

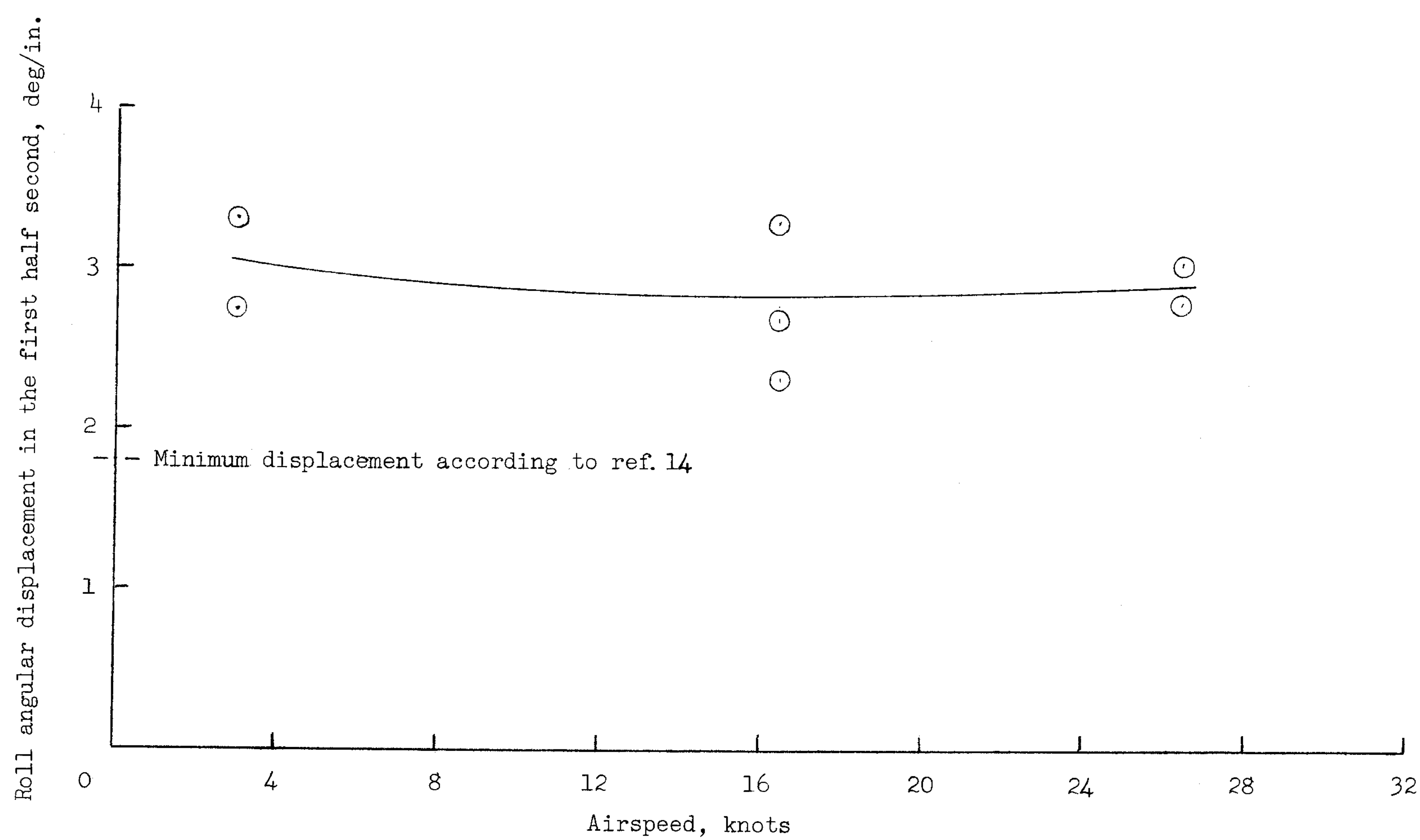


Figure 14.- Variation of roll response per inch of lateral stick with speed. Full-span flaps are automatically controlled according to schedule in figure 4.

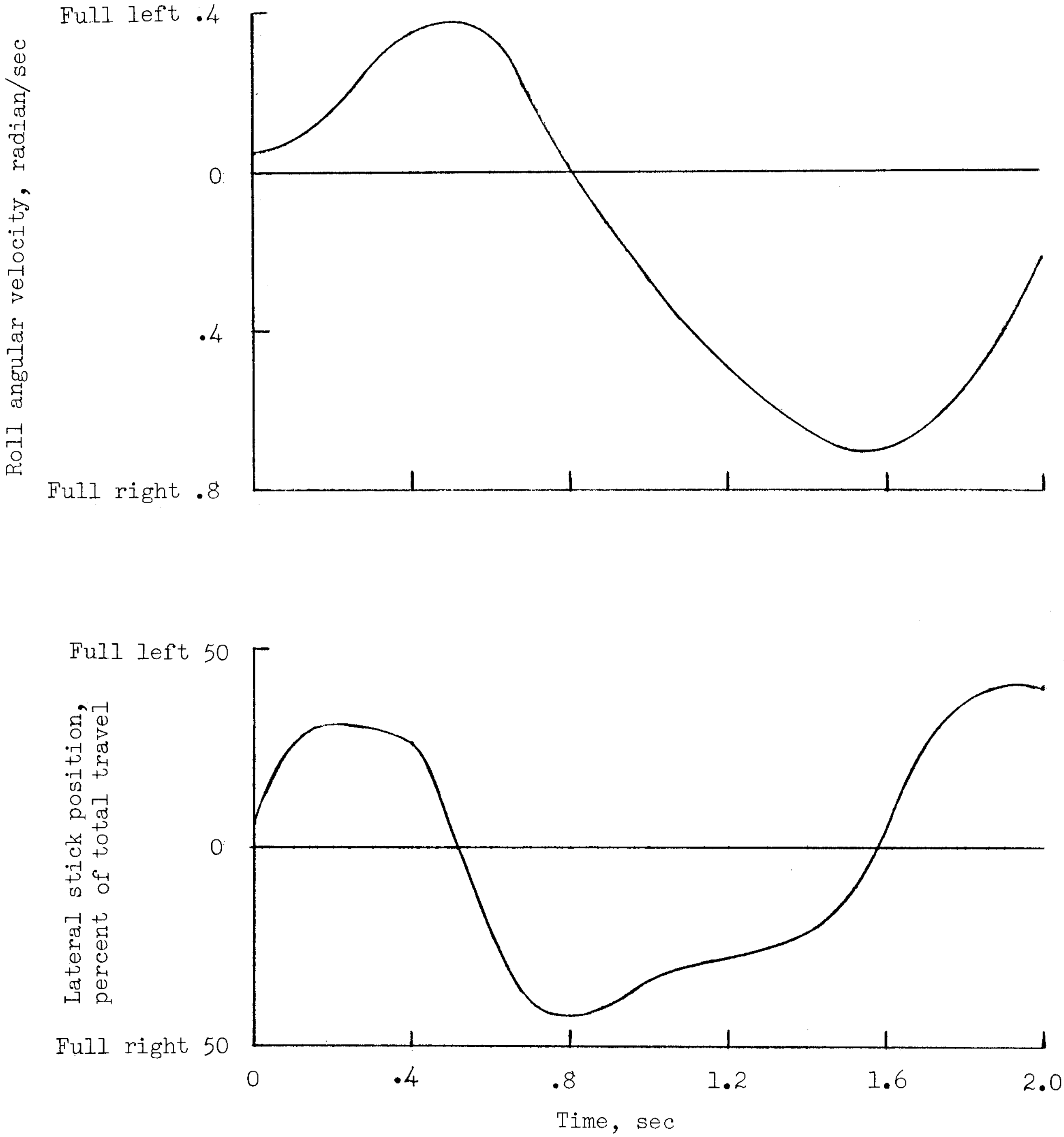


Figure 15.- Time history of typical lateral step input. $i_w = 67.4^\circ$; $\delta_f = 16.5^\circ$; $V = 16.7$ knots; and $P = 546$ hp.

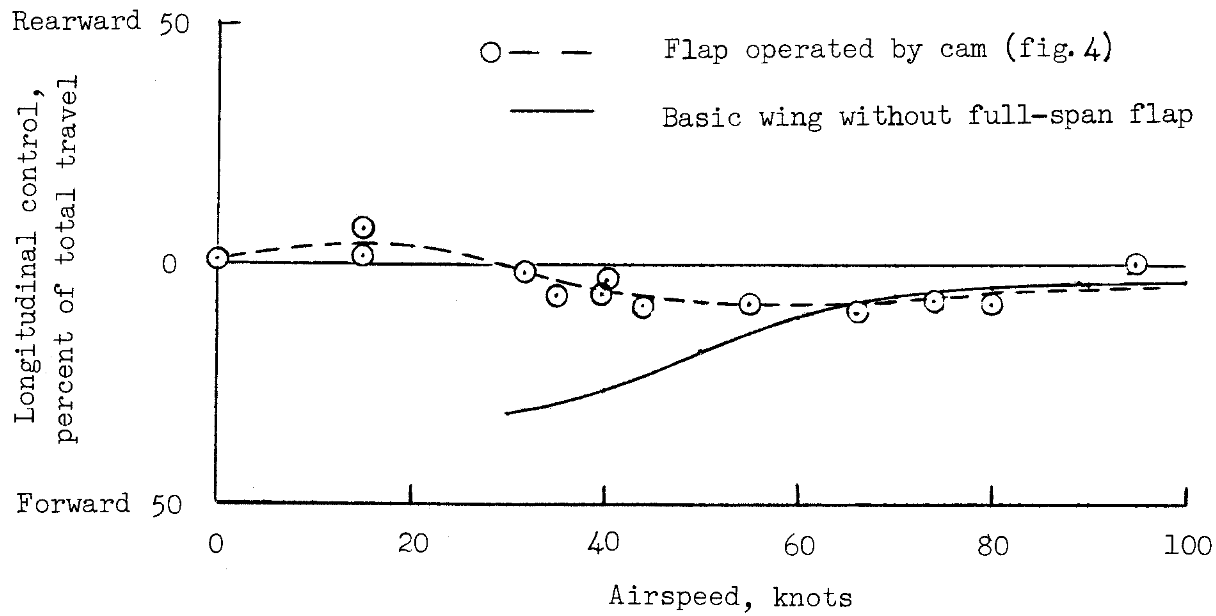


Figure 16.- Variation of longitudinal stick position with airspeed showing the effect of the full-span flap. Fuselage at a constant trim attitude.

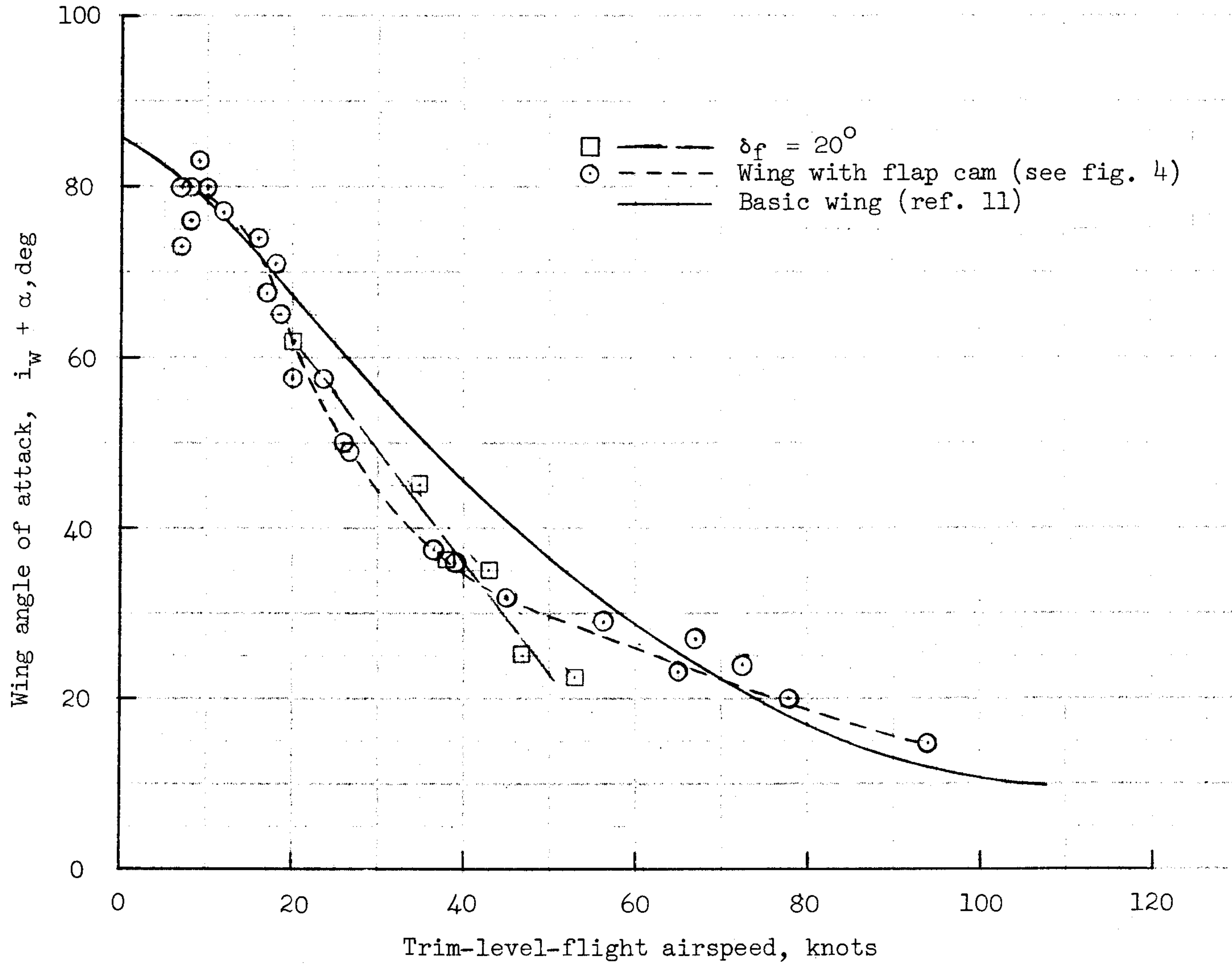


Figure 17.- Variation of wing angle of attack with airspeed.

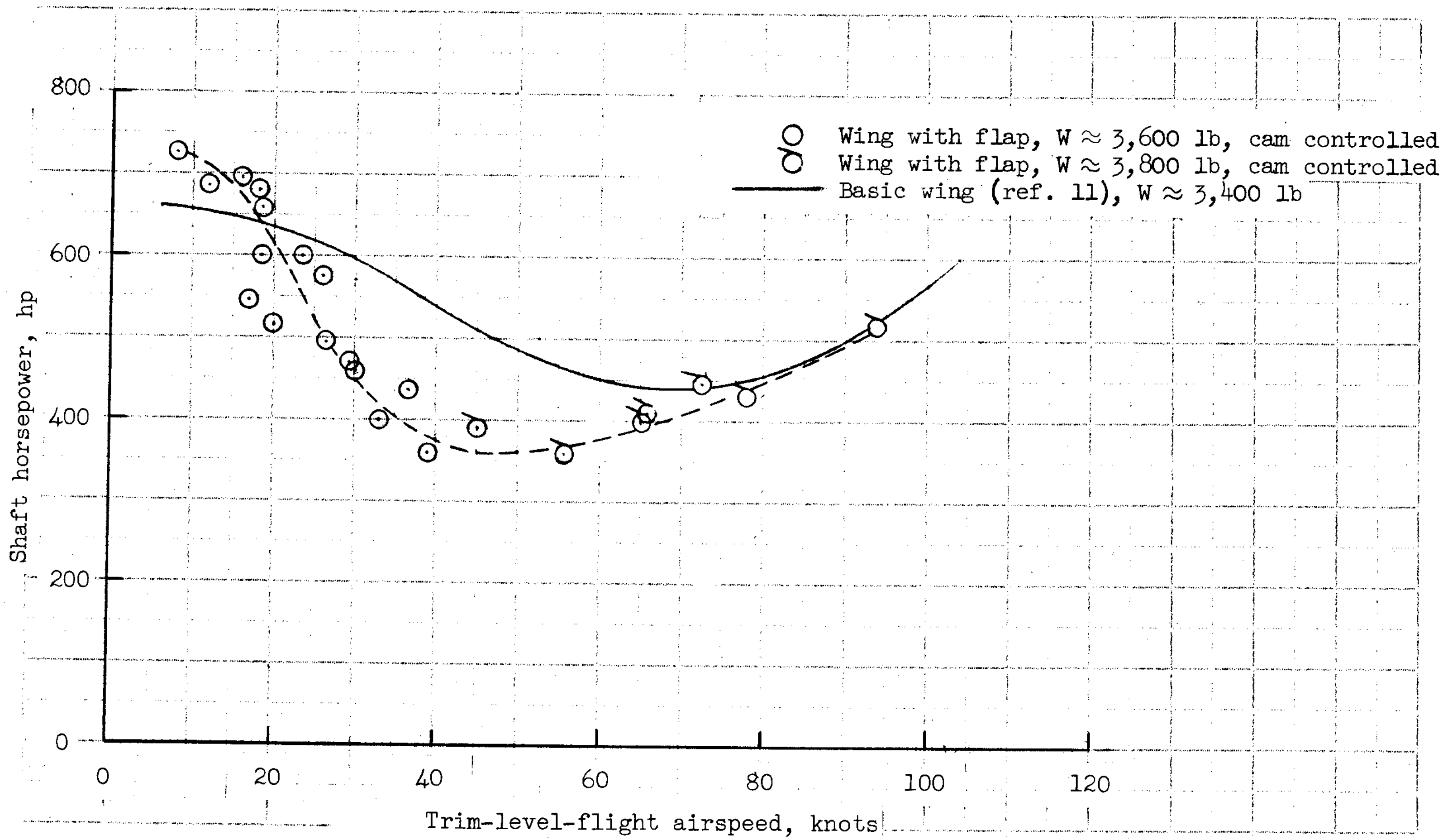


Figure 18.- Power-required curve of the test aircraft before and after wing modification.

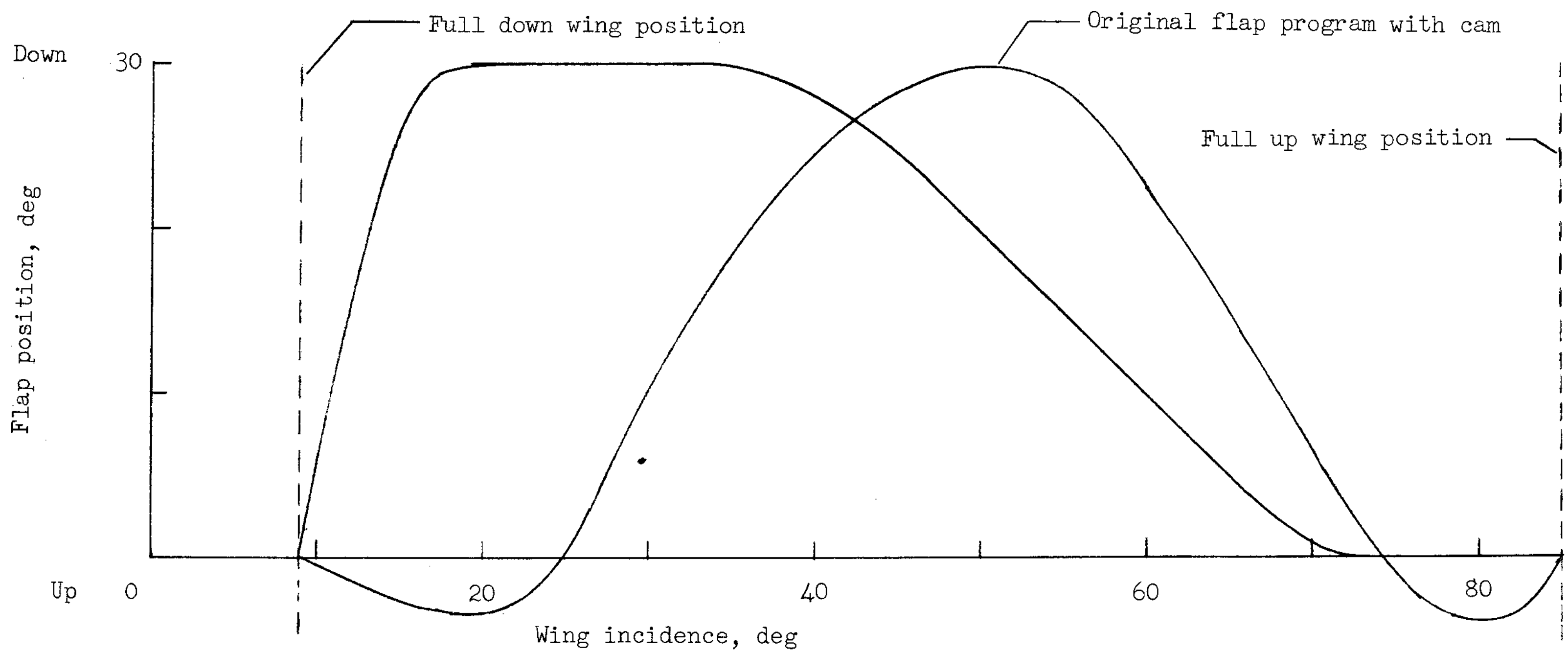
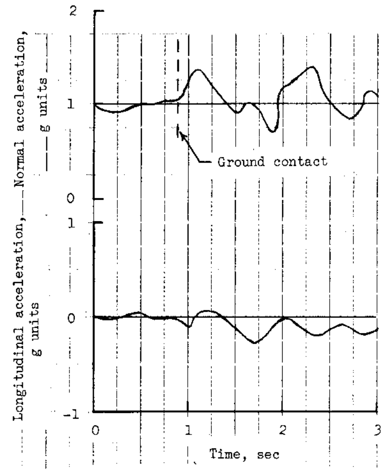
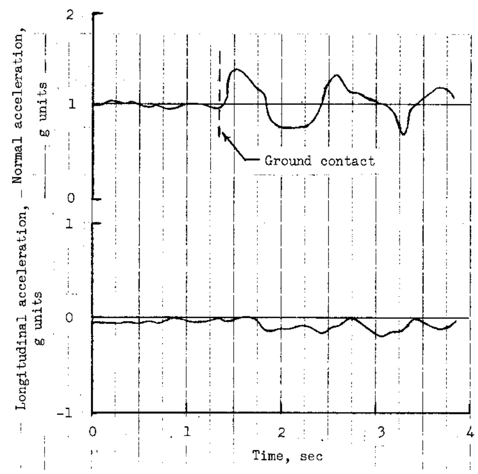


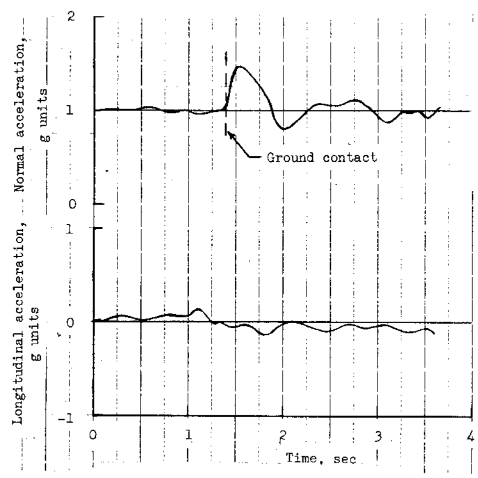
Figure 19.- Trailing-edge flap program with wing angle which should have provided more desirable characteristics for the VZ-2 compared with original flap program with cam.



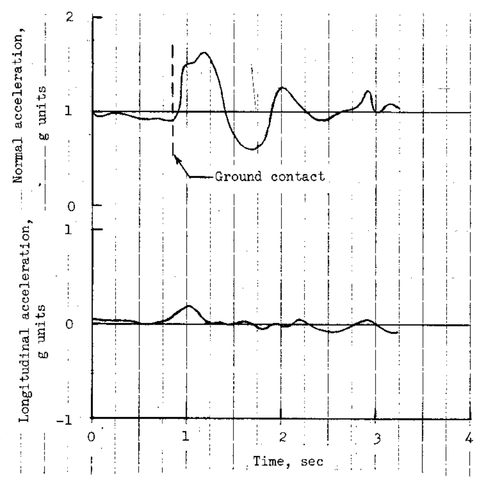
(a) V = 55 knots; $i_w = 30^{\circ}$; $\delta_f = 9^{\circ}$.



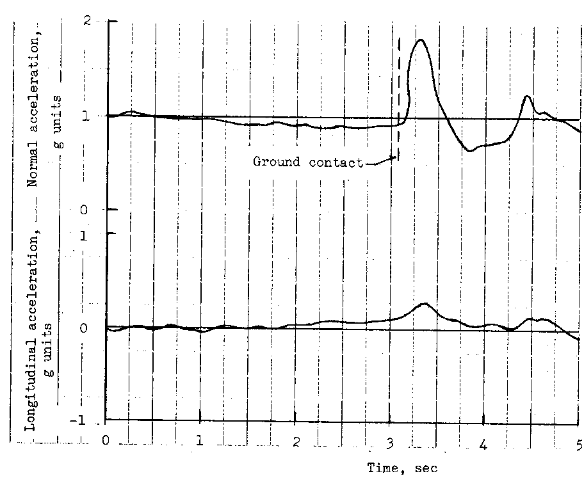
(b) V = 37 knots; $i_w = 40^{\circ}$; $\delta_f = 21^{\circ}$.



(c) V = 30 knots; $i_w = 50^{\circ}$; $\delta_f = 27^{\circ}$.



(d) V = 23 knots; $i_w = 60^{\circ}$; $\delta_f = 27^{\circ}$.



(e) V = 19 knots; $i_w = 70^{\circ}$; $\delta_f = 16^{\circ}$.

Figure 20.- Time histories of steady landing approaches showing the resulting normal and longitudinal accelerations for five wing incidence angles.

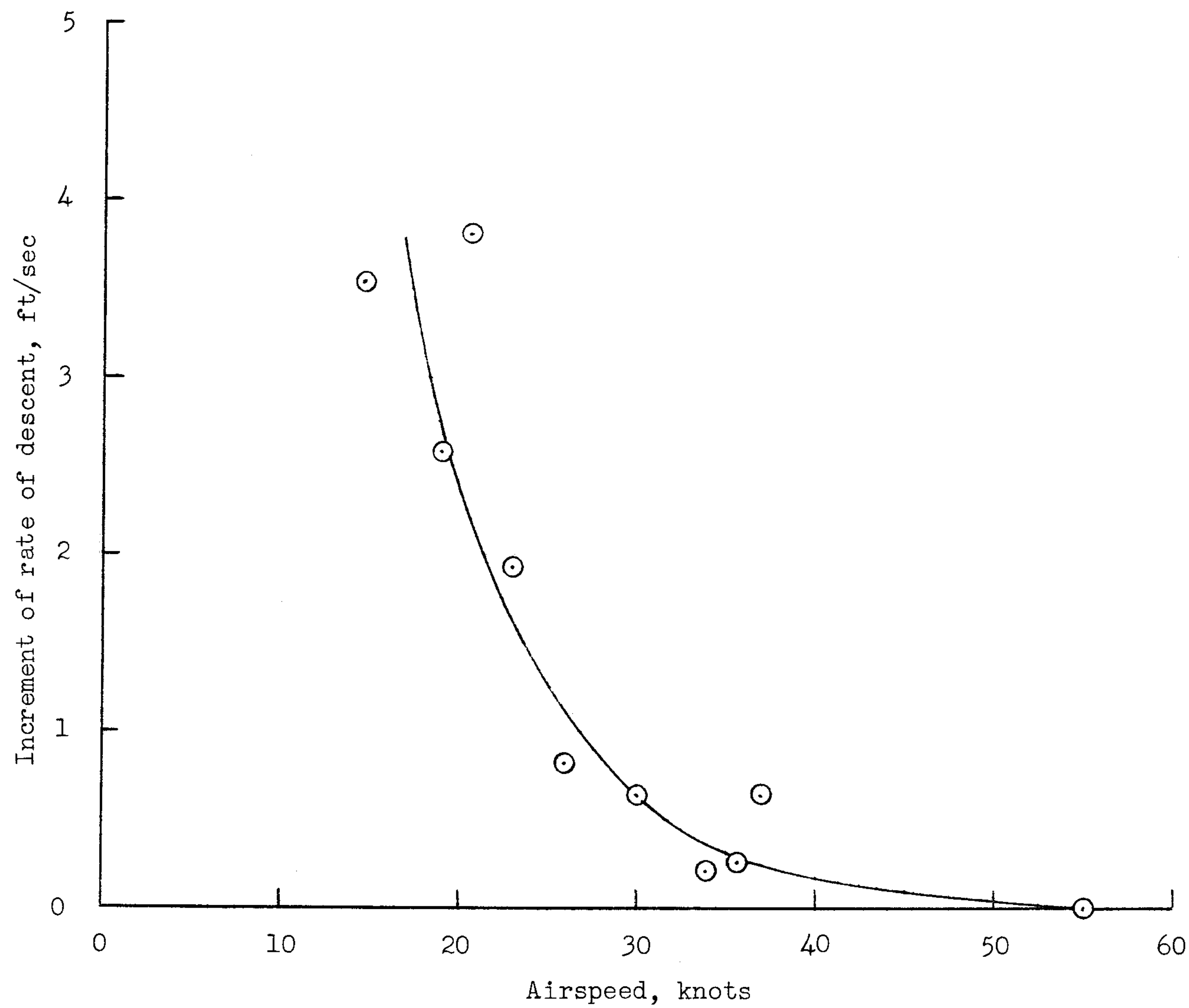


Figure 21.- Increase in steady-state rate of descent due to negative ground effect. (Negative ground effect appears at a height of approximately 10 feet.)

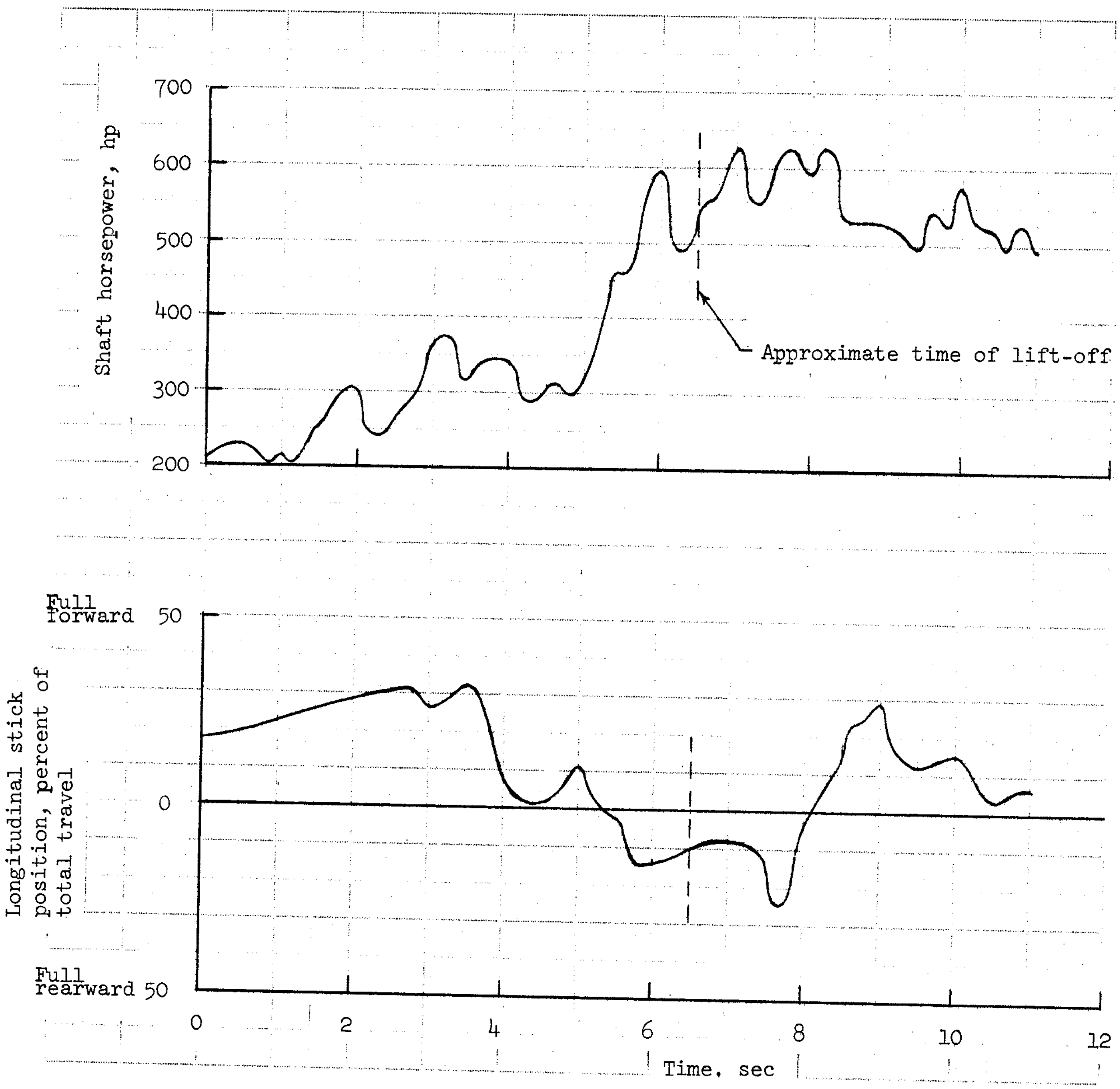


Figure 22.- Time history of take-off at a high wing incidence angle showing large amount of longitudinal trim change required. $i_w = 62^\circ$; $\delta_f = 26^\circ$.

NASA-Langley, 1965 L-4162